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Perceptive aspects of emergency signals

Hugo Fastl[1], Daniel Menzel[1], Matthias Müllner[2], Karl Wenzelewski[3], Holger Wigro[4]

[1] AG Technische Akustik, MMK, TU München {fastl@mmk.ei.tum.de, menzel@mmk.ei.tum.de}
[2] Hörmann GmbH Kichseeon {MMuellner@hoermann-gmbh.de}
[3] DIN Außenstelle Pforzheim {karl.wenzelewski@DIN.DE}
[4] Bundesamt für Bevölkerungsschutz und Katastrophenhilfe Bonn {Holger.Wigro@bbk.bund.de}

Dedicated to Prof. Dr.-Ing. habil. Helmut Fleischer on the occasion of his 65th birthday

Abstract

In Germany, reference time signals from an atomic clock are distributed via a long-wave radio station called DCF77. As a rule, both radio clocks and wrist watches set their actual time as well as the switching between summer and winter time using the DCF77. Apart from this service which started in the 1970ties, more recently studies are underway how to use the spare bits of the time code for civil protection emergency signals. A possible realization could be that emergency signals are radiated from smoke detectors.

In the framework of such a scenario, the suitability of different pure tone signals as emergency signals was studied in psychoacoustic experiments. The effects of different durations and repetition rates were assessed using the methods of random access as well as semantic differential. For the selection of the signals, the hearing ability in an ageing population was also taken into consideration. Moreover, signals were tailored in such a way to minimize possible confusions with other signals from alarm clocks, smoke detectors etc.

In the lecture, signals will be presented acoustically: on the one hand, signals which are most suitable for the intended purpose, and on the other hand signals which are less appropriate.

Keywords: Emergency signals, random access, semantic differential, DCF77.

1 Introduction

An early example of psychoacoustic studies on emergency signals represents the work of Fleischer and Blauert (1989). These authors studied public-address warning signals for typical environmental noise situations. Both outdoor and indoor scenarios were assessed and the spectral distributions of warning signals and environmental noise signals were found to be the key features. For the audibility of the warning signals, steady state-environmental noise turned out to be the “worst case”.
A study by Kuwano et al. (2007) addressed the subjective impression of auditory danger signals in different countries. Generally it was found that signals produced rather similar loadings for “safe-dangerous” in Boston, Munich, Oldenburg, and Osaka, i.e. in cities of USA, Germany, and Japan. Only for tone glides with silent intervals of more than 300 ms, discrepancies of more than two steps on a seven step scale showed up: Subjects in Boston rated the signals more on the safe side whereas subjects in Munich rated them more on the dangerous side.
In comparison to the studies mentioned above, the study presented here had to cope with several rather severe restrictions. The scenario addressed was as follows: In Germany, reference time signals from an atomic clock are distributed via a long-wave radio station called DCF77. As a rule, both radio clocks and wrist watches set their actual time as well as the switching between summer and winter time using the DCF77. Apart from this service which started in the 1970ties, more recently studies are underway how to use the spare bits of the time code for civil protection emergency signals. A possible realization could be that emergency signals are radiated from smoke detectors. Because of the limited frequency response of the transducers in the smoke detectors, broadband signals or frequency glides could not be used. Therefore, the suitability of different pure tone signals as emergency signals was studied in the psychoacoustic experiments. The effects of different durations and repetition rates were assessed using the methods of random access as well as semantic differential. For the selection of the signals, the hearing ability in an ageing population was also taken into consideration. Moreover, signals were tailored in such a way to minimize possible confusions with other signals from alarm clocks or smoke detectors.

2 Selection of Features for the Emergency Signals

2.1 Signal Frequency

Because of the limited frequency response and distortions of transducers typically used in smoke detectors, pure tone frequency signals were chosen. To warrant audibility of the emergency signals also in an ageing population, their frequency should not be too high. Figure 1 shows the age dependent hearing loss at different frequencies according to DIN EN ISO 7029 (2001). In particular at high frequencies, the average hearing loss increases dramatically with age. In order to reach sufficient audibility of the emergency signals, a maximum of 20 dB hearing loss was selected. This means for persons with 70 years of age that frequencies above about 2000 Hz can not be used.

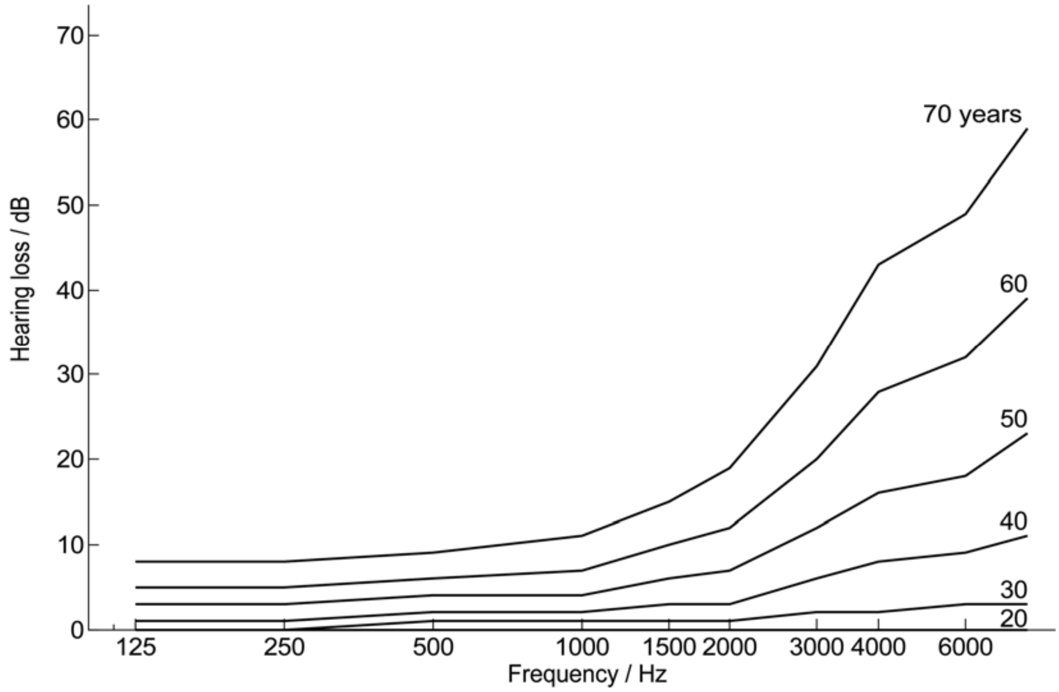

Figure 1 – Hearing loss as a function of frequency for different age groups according to DIN EN ISO 7029 (2001)

Moreover, it should be possible to easily distinguish the emergency signals from other signals usual in households like alarm clocks or smoke detectors. An analysis of the signals radiated by a typical smoke detector revealed a basic frequency of 3260 Hz, which was anyway out of the frequency range considered. A typical alarm clock produced signals with 2050 Hz basic frequency and strong harmonics. In consequence, also these measurements confirm the plan to restrict the frequency of the emergency signals to a frequency range below 2000 Hz. On the other hand, however, the transducers used in smoke detectors can not reproduce pure tones below 1000 Hz without significant distortions, in particular at the high sound pressure levels necessary for emergency signals.

Taking all the arguments given above into account, a frequency of 1500 Hz was chosen for the emergency signals to be used in the psychoacoustic experiments.

2.2 Minimum gap duration

The minimum duration of gaps between tone impulses required is governed by the reverberation time of the room in which the smoke detector radiating the emergency signals is installed. Long reverberation times could blur the gaps between tone impulses that the emergency signals would no longer be recognized. In order to choose some lower limit for the duration of temporal gaps, reverberation times and diffuse-field distances in typical living rooms have to be considered. According to Burkhart (1994) reverberation times in typical living rooms reach values around 500 ms, and diffuse-field distances values around 0.6 m. Since smoke detectors usually are mounted on the ceiling of a room, persons who should be warned are situated in the diffuse field. To warrant a clearly audible amplitude modulation, according to Fastl and Zwicker (2007, Fig. 10.3), a modulation depth of about 10 dB is necessary. Taking all features mentioned together, the temporal gap between two tone impulses should not fall below 100 ms.

2.3 Emergency Signals used in the Psychoacoustic Experiments

Based on the considerations described in detail in sections 2.1 and 2.2, we developed the emergency signals displayed in figure 2.

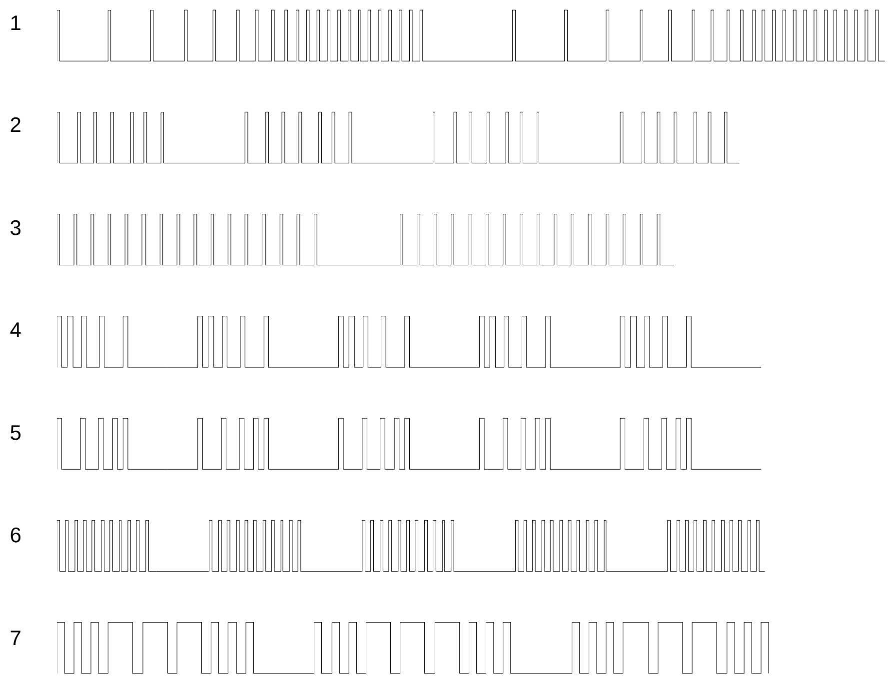

Figure 2 – Time patterns of emergency signals used in the psychoacoustic experiments. All impulses consist of pure tones at 1500 Hz.

The signals displayed in figure 2 can be characterized as follows:

1) Long pulse trains with decreasing gap duration
2) Groups of seven impulses with irregular gaps
3) Groups of 16 impulses with gaps of equal duration
4) Short pulse trains with increasing gap duration
5) Short pulse trains with decreasing gap duration
6) Groups of eleven impulses at minimum gap duration
7) SOS Signal

Table 1 gives the details of the temporal structure for the emergency signals used in the psychoacoustic experiments

Table 1 – Temporal structure of the emergency signals composed of pure tones at 1500 Hz.

Signal	Impulse duration / ms	Gaps between impulses / ms	Gaps between pulse trains / ms
1	50	700, 560, 450, 360, 290, 230, 180, 150, 120, 100, …, 100	1200
2	50	260, 176, 200, 238, 152, 190, 170	1000
3	50.2	198	1000
4	80	80, 120, 180, 270	1000
5	80	270, 180, 120, 80	1000
6	50	100	800
7	120, 370	130	880

3 Experiments

3.1 Subjects and presentation of sounds

Fourteen subjects with normal hearing and an age between 22 and 33 years (median 25 years) took part in the experiments. Sounds were presented diotically via electrodynamic headphones (Beyer DT48) with free-field equalization as described by Fastl and Zwicker (2007, p. 7). The experiments were performed in a soundproof booth.

3.2 Procedure Random Access

The procedure random access (Fastl 2000) allows a quick ranking of sounds in view of an intended purpose. In the present case, the suitability of signals as emergency signals should be rated. To this end, the following question had to be answered: “Please rate the signals presented with respect to their potential to prompt you to switch on your radio or TV”.
Subjects were presented a user interface as indicated in figure 3.

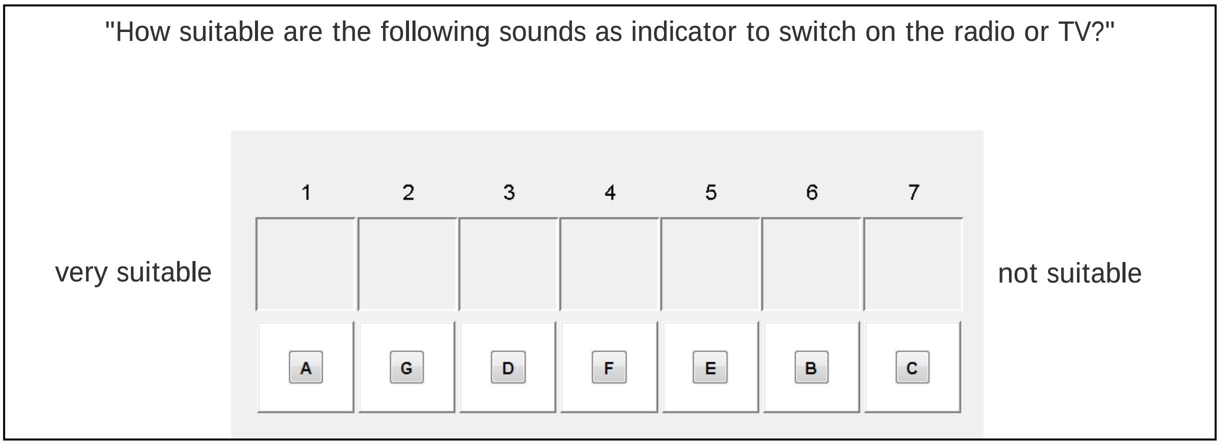

Figure 3 – User Interface for the procedure random access.

By clicking on one of the letters A through G one of the emergency signals illustrated in figure 2 was presented via headphones. By drag and drop the subject had to shift in the user interface of figure 3 the respective letter into one of the fields 1 through 7 in such a way that in the end, the most suitable signal should appear in field 1 and the least suitable signal in field 7. There was no time limit imposed, the subjects could listen to the signals as often as they liked, and could re-arrange them until they were satisfied with their choice. In three different sessions, three different scenarios were assessed.

3.2.1 Scenario sleep

In this scenario the subjects should imagine the situation that they are awakened by the respective signal from their sleep.

3.2.2 Scenario rest

In this scenario the subjects should imagine that they are sitting relaxed at home reading a book, when suddenly they hear the respective signal.

3.2.3 Scenario stress

In this scenario the subjects should imagine that they live in a region endangered for flooding, that the weather forecast predicts high waters, and that they suddenly hear the respective signal.

3.3 Procedure Semantic differential

In order to assess the subjective impact of the emergency signals, an additional experiment using the method of semantic differential was performed. Fourteen adjective pairs were chosen and evaluated along scales with seven steps. While the original adjectives were given in German, figure 4 shows the user interface with the adjectives in English translation.

aggressive								unobtrusive
dangerous								harmless
irritating								guiding
obtrusive								discreet
alarming								tiring
arousing								drowsy
worrying								calming
lively								lifeless
annoying								pleasant
expensive								cheap
known								unknown
modern								old-fashioned
loud								soft
unfriendly								friendly

Figure 4 – User Interface for the procedure semantic differential. Adjectives translated from German into English.

4 Results and Discussion

Figure 5 shows the results obtained with the procedure random access. Histograms of the rankings from 1 (most appropriate) to 7 (least appropriate) are displayed for the seven emergency signals S1 to S7. The respective centroid is given as number in parentheses on the top of each histogram, and as downward pointing triangle at its bottom. Since the three scenarios led to similar data, on top of figure 5, results averaged across all scenarios are displayed. The subsequent panels illustrate the data for the scenarios sleep, rest, and stress, respectively.

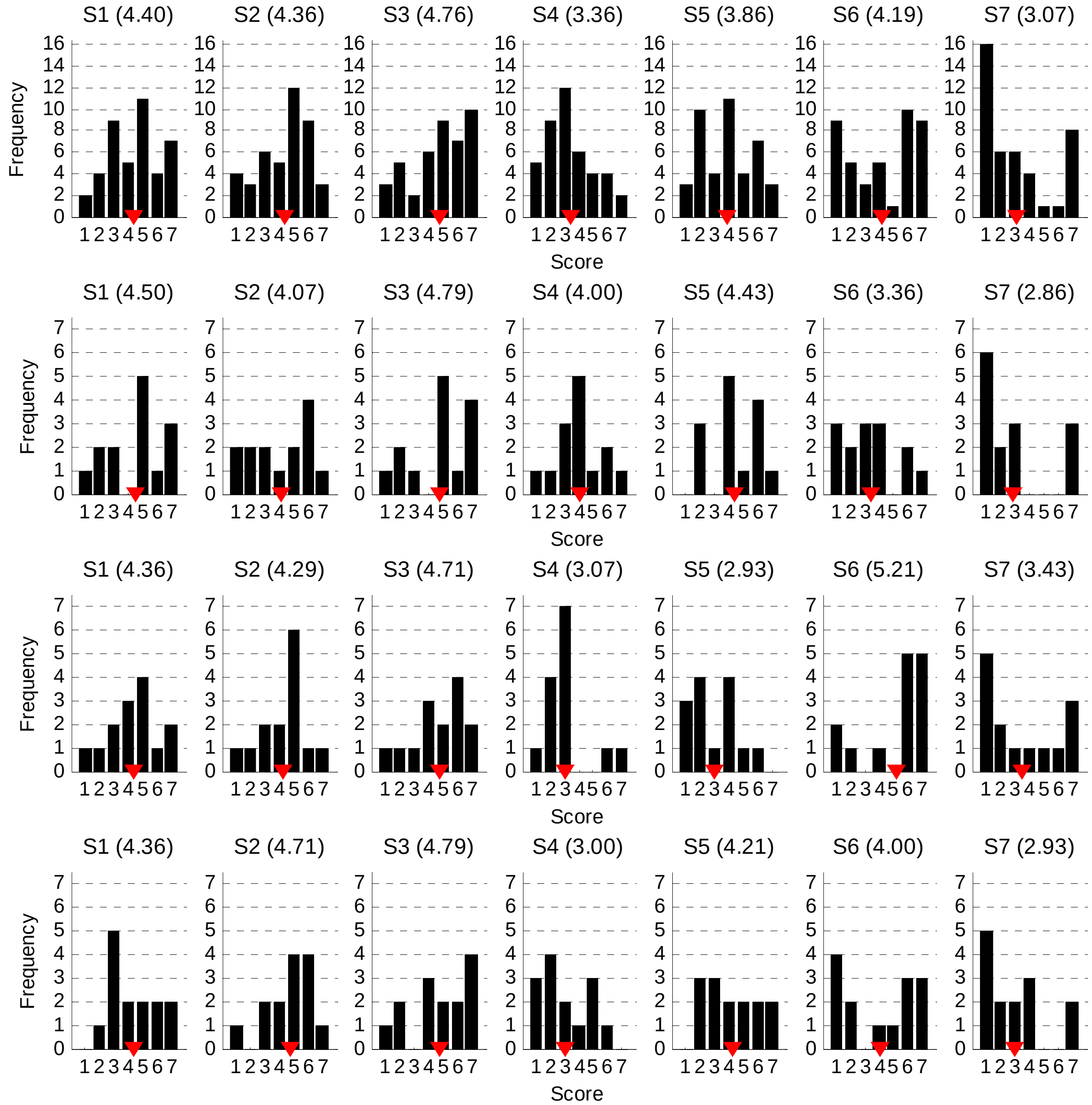

Figure 5 – Histograms of the rankings for the signals S1 through S7 with respective centroids as numbers in parentheses or downward pointing triangles at the abscissae. From top to bottom: all scenarios, scenario sleep, scenario rest, scenario stress.

The results displayed in figure 5 indicate that in particular signal 7, but also signal 4 are suitable in the given context as emergency signals. On the other hand, signal 1 and in particular signal 3 are less suitable.

Since with the procedure random access signals 7 and 3, respectively, were rated as most or least suitable, in figure 6 the results of the semantic differential are shown for these two signals.

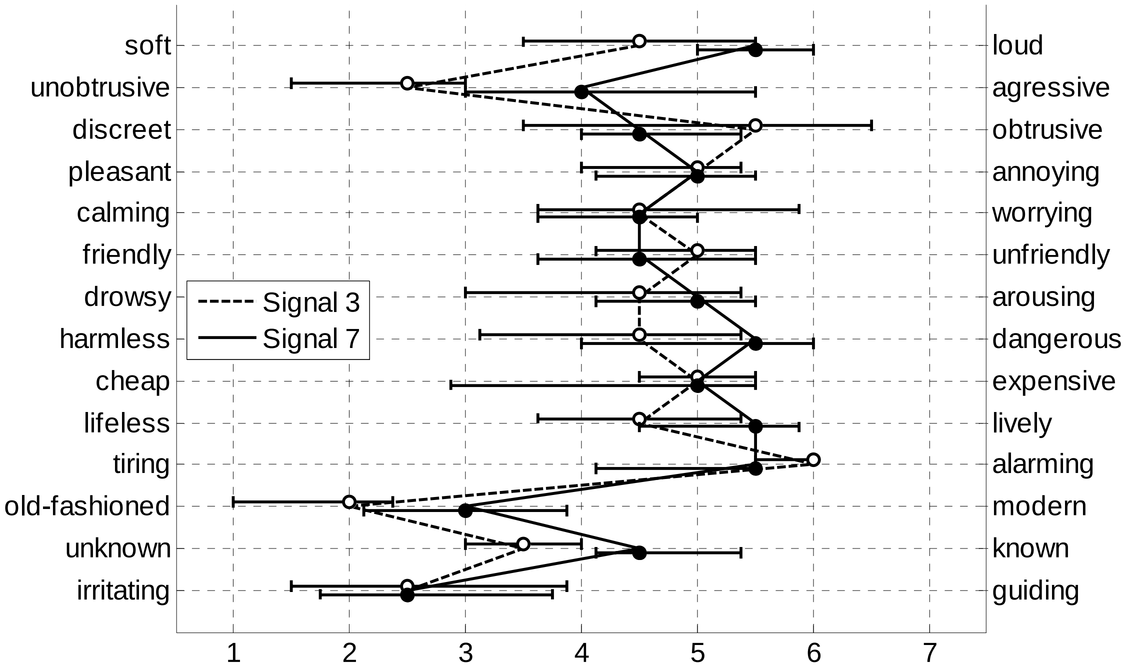

Figure 6– Semantic differential for signal 7 (solid) and signal 3 (dashed).

The data displayed in figure 6 suggest no dramatic differences between both signals. Nevertheless, higher values of at least one step for ratings of the adjectives loud, aggressive and dangerous for signal 7 are in line with the results from random access. On the other hand, signal 3 gets a slightly higher rating for the adjective alarming. However, it should be mentioned that the interquartile ranges largely overlap, and that on the basis of the semantic differential alone, all signals considered would be more or less suitable as emergency signals in the context considered.

5 Conclusion

The results presented in this paper can be interpreted in such a way that none of the signals developed would be completely unsuitable as emergency signal in the context considered. However, averaged over all scenarios, signal 7 (SOS) gets a better centroid ranking by 1.69 ranks on the seven rank scale than signal 3 (gaps of equal duration). Moreover, signal 7 gets higher loadings on adjectives like loud, aggressive and dangerous. Therefore, it seems particularly well suited as emergency signal. Also signal 4 (with increasing gap duration) seems to be well suited, whereas signal 1 (with decreasing gap duration) seems to be less appropriate.

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