EXPRESSIVE MUSICAL WARNING SIGNALS

Johan Fagerlönn

The Interacive Institute
Sonic studio
Piteå, Sweden
johan.fagerlonn@tii.se

ABSTRACT

Warning signals are often very simple and monotone sounds. This paper focuses on taking a more musical approach to the design of warnings and alarms than has been the case in the past. We present an experimental pilot study in which we explore the possibilities of using short musical pieces as warning signals in a vehicle cab. In the study, 18 experienced drivers experienced five different driving scenarios with different levels of urgency. Each scenario was presented together with an auditory icon, a traditional abstract warning sound, and a musical warning sound designed in collaboration with a composer. The test was carried out in an "audio-only" environment. Drivers were required to rate the perceived urgency, annoyance and appropriateness for every sound. They also had a chance to talk freely about the different warning signals. The results indicate interestingly that drivers may be able to understand the intended meaning of musical warning signals. It seems like the musical warning signals may prove useful primarily in situations of low and medium levels of urgency.

[Keywords: Warning signals, Music, Semantics.]

1. INTRODUCTION

Studies on abstract warning sounds and earcons have given us some understanding of the potential of using musical sounds in auditory interfaces. So far research has been focusing primary on issues such as making these sounds recognisable and easy to recall. Not much research has been focusing on trying to make them more pleasant and accepted by users. Development of music software has been remarkable rapid during the last 3-4 years, enabling composers with limited resources to create expressive and highly-realistic music using computers. In our work, we are examining how musical sounds can be further developed as warnings and alarms. This paper focuses on taking a more musical approach to the design of warnings and alarms than has been the case in the past.

2. NON-SPEECH BASED MUSICAL SOUNDS

Non-speech based sounds have an advantage over speech in that they are language independent and have the potential to be understood more efficiently and more rapidly. Today, there are several types of non-speech candidates that can be used as warnings and alerts (attention grabbing audio signals) in vehicles.

Abstract warning signals, a frequently used type of sound, have been the subject for several previous studies [1,2,3]. It is suggested that these sounds are capable of conveying different levels of urgency by modulation of various acoustic parameters; such as fundamental frequency, speed and pitch range [1]. Early studies on perceived urgency have resulted in general guidelines about how warning signals should be designed and mapped onto urgent situations, a principle known as urgency mapping.

Earcons are another type of synthetic, abstract sound for use in interfaces. Earcons make use of many possibilities offered by musical signals, to form unique sounds. By manipulation of different parameters, such as timbre, register and rhythm, hierarchical earcons with specific meanings can be created [4,5]. The effectiveness of earcons relies on the fact that people learn the structure of the sounds in which the information is contained.

3. DESIGNING PLEASURABLE SOUNDS

An issue for auditory interfaces in general is how to design sounds that are not annoying. Unpleasant warning signals are suggested to be one of the common-most reasons why users want to turn off warning systems [6]. Wiese et al. [7] examined warning signals specifically for in-vehicle information systems and suggested that annoyance can have a direct effect on the workload. It should be noted that annoyance is often a desirable quality in very urgent situations. However, in more everyday situations, it's important that the driver is able to keep focus on the road without getting distracted more than is absolutely necessary.

The majority of research carried out into annoyance and sound has focused on the physical characteristics of the sound, which are considered to be annoying. Edworthy et al.[1] and Heiller et al. [2] considered how basic acoustic parameters of sounds

contribute to their perceived urgency, which might be seen as a correlate to their potential to distract and annoy. An alert designed to be less urgent is also likely to be perceived as less annoying. However, abstract warning signals are often very simple and monotone sounds. In general they sound very mechanic and unmusical. The alerts are often not designed with other warning signals in mind. In many cases, one alert (a monotonous beep) may sound pretty the same as several other alerts. In our research we are interested in how we can change this view on warning signals by making them more expressive and musical. The many ways in which music can sound different can be utilized to design more distinguishable and recognizable warning signals. But the emotional and esthetical aspects of music are also interesting for future development of intuitive and pleasant warning signals.

4. THE LANGUAGE OF MUSIC

Ever since sound has been used to communicate information in human-machine interfaces, a number of authors have addressed the matter of using music [8, 9, 10], and yet, we have only begun to explore the potential of musical signals for use in auditory interfaces. Abstract warning signals and earcons are both examples of well tested musical sounds. Previous studies on these sounds can provide powerful guides in how to design functional warning signals. But music is a rich communication medium, and there is still much to find out about how to make use of musical expression and meaning. Gaver [10] outlined that auditory interfaces had so far utilized only a limited amount of the inherent potential in music. Since then, only a finite amount of work has been carried out to investigate new aspects of music in auditory interfaces. Bresin et al. [11] pointed out how ringing tones, alert sounds in computer programs, and musical logos can acquire pleasantness and reality by applying performance rules. Leplâtre et al. [8] investigated in a study how musical semantics can be exploited to create large hierarchies of sounds for use in areas such as telephone based interfaces.

Perhaps it is not surprising that the more expressive aspects of music have had such a reserved role in research on auditory interfaces so far. Music is a very complex signal and exactly how music is perceived and can affect us has never been a straightforward issue. This is however not an issue for composers, who happily exploit the potential of music to create moods and atmospheres without needing to point out exactly how they do it.

4.1. Music and emotion

Music is sometimes referred to as the language of emotions. Exactly which emotions music can express and induce in listeners is currently an ongoing discussion within the area of music psychology. However, the most common belief is that music can be used to express a number of basic emotions. For instance, we are most likely to recognise music as happy, sad or fearful [12]. Gabrielsson [13] suggested that music researchers should distinguish between the emotions that individuals perceive in music and the emotions they feel or experience as a result of engaging in music.

4.2. Music to represent physical objects and states

Sometimes music is designed to represent the sound of specific events and objects. This can be done in several ways.

Firstly, by direct imitation of something which emit sound of definite pitch, such as a human scream.

A second way is by approximate imitation of a sound source with indefinite pitch, such as a thunderstorm.

A third way is by suggestion or symbolization of a purely visual thing. In this case the composer is trying to use sounds which have an effect on the ear which is similar to that which the appearance of an object has on the eye [14]. In this way, unstructured tones can give the listener the impression that something is not as it should be. An unexpected event in the music can be used to represent unusual events that need further attention. Rapid repetition of one note or a rapid alternation between two or more notes (tremolo) can produce an unsettled effect and represent something deemed to be insecure.

4.3. Music and basic acoustic parameters

Since music is a kind of sound, it is reasonable to believe that basic acoustical parameters used to convey urgency in warning signals have a similar effect in music. Tempo (speed), loudness and segments of dissonance are all parameters suggested to change the perceived urgency in warning signals. These values are often used in music to express anger and fury. However, what music expresses seems to depend on the relationship between the musical parameters, rather then by individual parameters. For instance, minor key is often used to express sadness in music. But in combination with a fast tempo the perceived meaning of the piece can change drastically.

4.4. Music in film and computer games

Music is used to create atmospheres and enhance experiences in various areas such as film and computer games. The music continuously adds complementary information to the visual channel along with sound effects and dialog and is often tied to objects and events in effective ways. One characteristic example is the main title from John Williams soundtrack to the film Jaws. Here, acoustical properties reflect different qualities of the shark, such as size (register) and movement (tempo). The horn is used to a great extend, an instrument traditionally associated with hunting. As the shark approaches, the tempo and the intensity of the music increases. Even though the shark is hidden under the surface and can't be seen, the perceived urgency of the situation increases.

5. THE EXPERIMENT

In areas such as movies and computer games listeners, consciously or unconsciously, accept music as a medium for communication. However, it is still uncertain whether we are ready to understand and accept music for this purpose in an environment such as a vehicle cab. To explore this issue further we performed an experimental pilot study. The intention with this study was not to investigate exactly how musical parameters correlate to perceived properties of musical sounds. But rather to increase our understanding of how musical warning signals are

perceived by drivers in general, and to point out potential future research topics and applications. Our aim was to find answers to four questions:
Is it likely that a driver will recognize music as a sign for something that is dangerous / important for themselves and others?
Is it likely that musical signals are capable of conveying different levels of urgency in the driver's unique environment?
Is it likely that a driver will find musical sounds annoying?
And finally, how appropriate do drivers consider musical warning signals to be?
If a sound is going to be a successful warning signal, it must be able to convey a feeling of danger and/or importance in some way. But warning signals and alerts can be implemented in a vehicle to serve a variety of functions, some of them will be more important / urgent than others. If musical warning signals are to be used in a vehicle cab to any great extent, they must be able to convey different levels of urgency. It is also of importance to find out whether drivers will find musical signals annoying. Even though the musical sounds that were used in this study are only examples of how musical warning signals can be designed, our hope was to get some indication of whether drivers find more musical warnings to be annoying in general. The intention of our last question was to obtain some indication of what kind of auditory signals experienced drivers prefer and expect to hear in different kinds of situations.
To get some insight into how musical warning signals stand against other potential types of warning signals, traditional simple abstract warning signals and auditory icons were included in the test.

5.1. Situation urgency evaluation

To begin with, a situation urgency evaluation was carried out to collect experienced drivers judgement on a range of driving scenarios. 13 experienced car drivers, 8 males and 5 females, took part in the evaluation. Their age ranged between 25 and 55, with an average of 37.7. To count as an experienced driver the subject was required to have at least 5 years of driving experience and drive more then 10000 km every year.
16 driving scenarios were selected for evaluation. The drivers were required to rate the situations using rating scales ranging from "not at all urgent" to "very urgent". Five situations, which differed consistent in their judged urgency, were selected for the main experimental study: two low-urgency scenarios (open door and low air pressure in a tyre), two medium-urgency scenarios (children in the road environment and slippery road), and one high urgency scenario (head-on collision).

5.2. Participants

18 experienced car drivers, 11 men and 7 females, participated in the main study. They ranged in age from 24 to 55, with an average age of 31.8. All subjects in the main study had normal hearing and 7 had a musical background.

5.3. Stimuli

The abstract warning signals were pulses of synthetic sound that were not thought to convey any type of meaning to drivers. Each abstract sound consisted of four or more pulses in a distinct pattern. The sounds were designed to convey different levels of urgency with inspiration from previous studies on perceived urgency carried out by Edworthy et al. [1]. The idea was to make them sound like characteristic examples of abstract warning signals and alerts commonly used in vehicles. Short descriptions of the abstract warning signals are presented in table 1.
Quite a lot of effort was put into designing auditory icons with clear and direct connections to the driving scenarios. A number of sounds were created and their comprehensibility was judged by a panel of three people. On the basis of panel feedback the sounds were changed and tested on the panel once again. After that, five sounds were selected to be used in the study. Four of them had an iconic relation to the driving scenario. One of the sounds (slippery road) was metaphorically mapped onto the scenario. The auditory icons are presented in table 2.
The musical sounds were designed in collaboration with a composer. To convey urgency these sounds used musical structures typically used to express fear, anger and anxiety in music such as tremolo, thrill, unexpected events, and unstructured tones and rhythms. The sounds were created using high quality orchestral samples from the Vienna Symphonic Library sample archive. A large number of short pieces with different musical styles were created and evaluated by the composer and the experimenter. Finally, five pieces were selected for the test. The musical warning signals are presented in table 3.
The abstract warnings, musical sounds and auditory icons were not exactly equal in length but ranged between 3 and 5 seconds. All sounds were normalized using normalization software.

Scenario	Description
Door open	Low fundamental frequency (262 Hz). Speed change – slowing down (115 – 35 BPM).
Low air pressure in a tire	Low fundamental frequency (262 Hz). Slow speed (60 BPM).
Slippery road	Medium fundamental frequency (391 Hz). Three rapid pulses repeated three times.
Children in the road environment	Medium fundamental frequency (391 Hz). Moderate speed (120 BPM).
Head-on collision	Cluster of dissonant frequencies (150-1200 Hz). Fast speed (210 BPM).

Table 1: *Description of the abstract warning signals*

Scenario	Sound	Mapping
Door open	A car door opening and making a creaking sound	Iconic
Low air pressure in a tire	Bursts of compressed air hissing out from a tube	Iconic
Slippery road	Sponge rubbed against a wet surface	Metaphorical
Children in the road environment	Children playing in playground	Iconic
Head-on collision	Car horn getting closer and closer.	Iconic

Table 2: *Description of auditory icons*

5.4. Procedure

The experiment was conducted using a within-group design in which all 18 drivers listened to all three types of sound. The idea was to isolate the effect of the sound as much as possible. For this reason, the tests were carried out in an "audio-only" environment without any visual components. (We are aware of that visual input can have a considerable impact on how the situation is judged in a real-life condition.) The sounds were presented using a pair of Sennheiser HD 570 headphones. The subjects experienced the warning sounds in a realistic sound environment representing the environment of a car interior. Every time an alarm was triggered the drivers were required to rate the perceived urgency of the situation and the perceived annoyance of the sound. The rating was performed using rating scales ranging from "not at all urgent" to "very urgent" and "not at all annoying" to "very annoying".

After the judgements, the meaning of the sounds was revealed and the drivers were given a chance to listen to the sounds again. They were then required to rank the sounds from 1-3 on the basis of how appropriate they felt the sounds were as warning signals for the particular situations. At this point, the drivers also had a chance to talk freely about the different sounds. Since the efficiency in using auditory icons as warning signals depends strongly on the listeners' ability to make the necessary association, it was of special interest to know whether the meaning of auditory icons were recognized. All comments made by the drivers were noted by the experimenter.

5.5. Results

Figure 1 shows average perceived urgency scores for musical sounds, auditory icons and abstract sounds. The musical sounds were able to convey urgency, and they were also rated as more urgent as scenarios became more urgent. Double tailed paired Student's t-tests were performed to examine whether there were significant differences in perceived urgency for different sounds.

Significant differences ($P<0.05$) were found for the musical sounds representing open door (*door*) and low air pressure in a tyre (*tyre*), *door* and *slippery road*, *tyre* and children in the road environment (*children*), *tyre* and *children*. No significant difference was found between the musical sounds representing *children* and head on collision (*collision*). Perceived urgency averages ranged from 9.9 to 69.3 for musical sounds.

For the abstract warning signals highly significant differences ($P<0.01$) were found for the sounds representing *door* and *slippery road*, *tyre* and *slippery road*, *slippery road* and *collision*, *children* and *collision*. Perceived urgency averages ranged from 41.6 to 91.6. A highly significant difference ($P<0.01$) was found between the musical and the abstract sound representing *collision*.

For auditory icons significant differences ($P<0.05$) were found for the sounds representing *tyre* and *children*, *children* and *collision*. Slippery road was scored lower than expected by the drivers. Perceived urgency averages ranged from 10.3 to 74.8 for auditory icons.

Standard deviations were calculated to examine differences in spread around the means between different sound types. However, no considerable difference was found between abstract sounds, musical sounds or auditory icons. This indicates that the drivers had no more difficulty in judging the musical sounds than the abstract sounds. Abstract warnings were in average rated as being more urgent than musical sounds and auditory icons for all scenarios.

Scenario	Instruments	Description
Door open	Viola, violin, cello	String ensemble is playing a sustained cord (G sus4) with additional thrills. Harp is playing the same chord in an arpeggio.
Low air pressure in a tire	String ensemble, harp	The cello is playing a sustained low pitched tone (C2) with the viola one octavo above playing C3 with tremolo. Violin is playing a sustained tone, C5 (two octaves above the viola). Crescendo in the first half of the piece, diminuendo in second half.
Slippery road	Piano, string ensemble, timpani, synth pad.	String ensemble and synth pad are playing an ambient, sustained cord (Db bass with added $b9^{th}$ and $+11^{th}$ note). Piano is playing a rhythmically unstructured pattern, high register arpeggio figure. Piece ending with a timpani and piano cord accent.
Children in the road environment	Timpani, String quartet, marimba	Marimba and mid strings are playing a six note melody, repeated 2 times. Timpani play rhythmic accents. The piece ends with a high pitch medium dissonant cord. It is based on a Low G bass and strings playing 4^{th} intervals
Head-on collision	String quartet	High pitch dissonant tones. Aggressive and percussive articulation. (Ascending major second intervals with a low G bass note)

Table 3: *Description of the musical sounds*

Figure 2 shows the perceived annoyance ratings for all three types of sounds. Abstract warnings, auditory icons and musical sounds were all scored less pleasant as scenarios became more urgent. Highly significant differences ($P<0.01$) in perceived were found for the musical sounds representing *collision* and all other musical sounds, and between *door* and all other musical sounds. The musical sounds were in average rated as less annoying than the abstract warning signals in all scenarios. But whether there seems to exist any general difference between the two sound types was not statistically tested. The abstract sounds were also consistently rated as more urgent than the musical warning signals, which may have an impact on perceived annoyance.

Figure 3 shows the appropriate ratings for all three sound types. The musical sounds were rated to be less appropriate as scenarios became more urgent. No such trend was found for the abstract warning signals or auditory icons. The auditory icon representing children in the road environment was found to be the most appropriate sound for that scenario. The auditory icon for *slippery road* was found to be least appropriate sound for that particular scenario. The abstract warning sound was rated to be very appropriate in the most urgent scenario, whereas the musical signal was rated to be the least appropriate sound for that scenario.

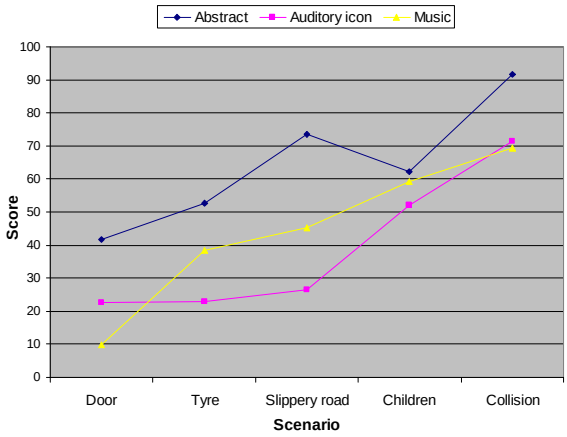

Figure 1. *Mean scores for perceived urgency*

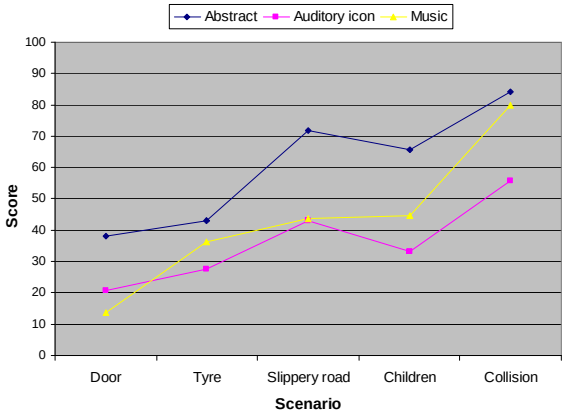

Figure 2. *Mean scores for perceived annoyance*

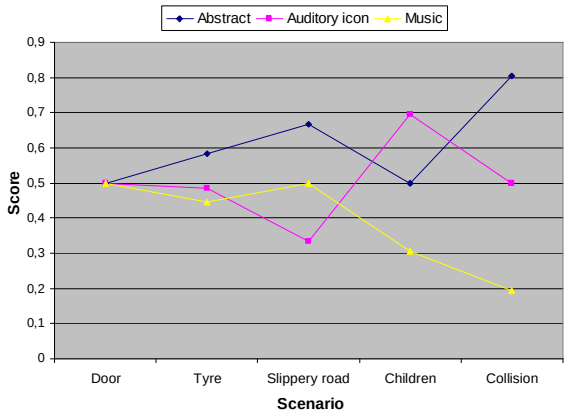

Figure 3. *Mean scores for appropriateness*

6. DISCUSSION

The result of this study indicates that the drivers were able to understand the intended meaning of the musical sounds. The musical sounds that were thought to convey a higher level of urgency were on average rated as more urgent, and they successfully conveyed low and medium levels of urgency. The musical sounds however did not succeed very well in conveying a very high degree of urgency. When the drivers had a chance to talk freely about the sounds, they sometimes mentioned that the musical sounds simply did not sound dangerous enough, particularly in the more urgent situations. A couple of them said "*it sounds like in a movie*". The drivers also rated the musical sounds to be less appropriate as the situations became more urgent. The abstract warning signal was rated as very appropriate in the most urgent situation. Several of the drivers said: "*this situation calls for something that sounds alarming, something that will wake me up*".

The musical sounds were in general not perceived as particularly annoying. An exception was the sound representing the head-on collision scenario. However, this sound was also the only musical sound that reminded noticeable of a traditional alarm sound. When designing the musical sounds we realized that it was quite difficult to design high urgency musical sounds merely using the music-specific parameters. These sounds unintentionally tended to sound similar to usual abstract warning signals.

The auditory icons performed pretty much as predicted in perceived urgency and they were not rated as particularly annoying. They were also considered to be fairly appropriate warning signals. The auditory icon representing children in the road environment was the easiest one to understand according to the drivers. This sound was also rated as the most appropriate sound for that particular scenario.

However, in some cases the drivers completely misinterpreted the meaning of the auditory icons. For instance, one driver thought the sound representing low air pressure in a tire was supposed to represent a hissing sound from a heavy truck. Consequently, this driver rated the situation as very urgent. The sound representing slippery road was the most difficult auditory icon to understand according to the drivers and the sound caused a considerable amount of confusion. The differences in perceived urgency ratings between different drivers were higher for this particular

sound than for any other sound used in the experiment. This verifies the importance of using very comprehensible and "direct" auditory icons, especially in rare situations.

Auditory icons are suggested to have the potential to cause inappropriate user actions [15]. A discussed method to increase the redundancy of auditory icons would be to manipulate various acoustic parameters of the sound to make them sound urgent [15, 16]. Another, alternative way to reduce the risk of unexpected user actions would perhaps be to present auditory icons concurrently with musical sounds. Whereas the auditory icon gives the driver associational information (what it is that we hear) the musical sound carries complementary information about urgency level (how important it is). The musical signal could further be used to help drivers distinguish warning messages from each other. Like musical parameters are used to make earcons distinguishable, timbres and melodies can be used to build families of warning sounds, and make warning sounds part of more overall theme.

The abstract warning signals successfully conveyed medium and high levels of urgency. The perceived urgency and annoyance seems to follow the same pattern. Drivers consistently rated them as appropriate warning signals. This was however not surprising, since drivers are probably used to hear this kind of auditory warning signals in various environments and contexts. In the 'children in the road' environment scenario, the musical sound conveyed an equal level of urgency as did the abstract warning signal. The musical sound was rated to be considerably less annoying. Still, drivers rated the abstract warning as more appropriate. This phenomenon may be an indication that traditional warning signals may have a particularly strong position. The fact that these "alarming" sounds are strongly associated with danger among drivers is worth some considering when designing alarms, even though the suitability of a warning signal depends on many different factors such as reaction time, accuracy and perceived annoyance.

7. CONCLUSION AND FUTURE WORK

In this paper we presented an experimental pilot study, in which we explored the potential of using expressive musical sounds as warnings and alerts for in-vehicle use. The results indicate interestingly that drivers may be able to understand the intended meaning of the musical warning signals. It seems like the musical sounds may prove useful primarily in situations of low and medium levels of urgency. Traditional abstract warnings may however still be preferable in very urgent situations. Auditory icons may be the best alternative in situations where comprehensible and familiar sounds can be used.

Future research can take several directions. It would be preferable to verify our theories from this study in a more extensive investigation. This study would include a larger number of musical warning signals. Accept from urgency, annoyance and appropriateness, it would also be interesting to investigate how musical warning signals perform when it comes to reaction times and accuracy. It should be pointed out that the musical sounds used in this study are examples of how musical warning signals can be designed. Further research is needed to determine more exactly how these sounds should be designed.

An alternative future application for musical sound can be to present them concurrently with auditory icons or environmental sounds. This may be an interesting way to make auditory warnings more redundant and decrease the risk of unexpected user actions.

8. REFERENCES

[1] Edworthy, J., Loxley, S., and Dennis, I., Improving auditory warning design: relationship between warning sound parameters and perceived urgency, *Human Factors*, vol. 33, no. 2, pp. 205 – 231, 1991.

[2] Hellier, E.J., Edworthy, J., and Dennis, I., Improving auditory warning design: Quantifying and predicting the effects of different warning parameters on perceived urgency, *Human Factors*, vol 35, no. 4, pp. 693-706, 1993.

[3] Guillaume, A., Drake, C., Rivenez, M., Pellieux, L and Chastres, V. Perception of urgency and alarm design. In *Proceedings of the 8th International Conference on Auditory Display*. 2002. Kyoto. Japan.

[4] Brewster, S.A., Providing a structured method for integrating non-speech audio into human-computer interfaces. 1994, University of York, UK.

[5] M. Blattner, D., Sumikawa, and R. Greenberg, Earcons and Icons: Their Structure and Common Design Principles, Human-Computer Interaction, vol 4, no 1, pp. 11-44, 1989.

[6] Block FE, Nuutinen L, Ballast B. Optimization of alarms: A study on alarm limits, alarm sounds and false alarms intended to reduce annoyance. *J Clin Monit Comput*, vol 15, no 2, pp 75-83, 1999.

[7] Wiese, E., Lee, J. D., Effects of multiple auditory alerts for in-vehicle information systems on driver attitudes and performance. *In Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*. 2001. Santa Monica, CA. USA.

[8] Leplâtre, G., Brewster, S.A. An investigation of using music to provide navigation cues. *In Proceedings of ICAD'98*. 1998. Glasgow. UK.

[9] Alty, J. L. Can we use music in human-computer interaction? *In Proceedings of HCI'95*. 1995. Cambridge. UK.

[10] Gaver, W. W., Auditory interfaces, In M. G. Helander, T. K. L. Landauer and P. Prabhu (Eds.) *Handbook of Human-Computer Interaction*., Amsterdam: Elsevier Science. Second Edition, 1997.

[11] Bresin, R., Friberg, A**.** Expressive musical icons. In *Proceedings of the 2001 International Conference on Auditory Display*. 2001. Helsinki. Finland.

[12] Nawrot, E. S., The perception of emotional expression in music: Evidence from infants, children and adults. *Psychology of Music*, vol 31, no 1, pp 75–92, 2003.

[13] Gabrielsson, A., Emotion perceived and emotion felt: same or different?, *Musicae Scientiae*, Special Issue 2001-2002, pp 123-147, 2002.

[14] Cooke, D., The Language of Music, 1959, London: Oxford University Press.

[15] R. Graham, "Use of auditory icons as emergency warnings: evaluation within a vehicle collision avoidance application," *Ergonomics*, vol. 42, pp. 1233-1248, 1999.

[16] Stevens, C., Brennan, D., & Parker, S. Simultaneous Manipulation of Parameters of Auditory Icons to Convey Direction, Size, and Distance: Effects on Recognition and

Interpretation. In *S. Barrass & P. Vickers (Eds.) Proceedings of the 10 th International Conference on Auditory Display*. 2004. Sydney. Australia.