MASTER

Sound management in a truck cabin

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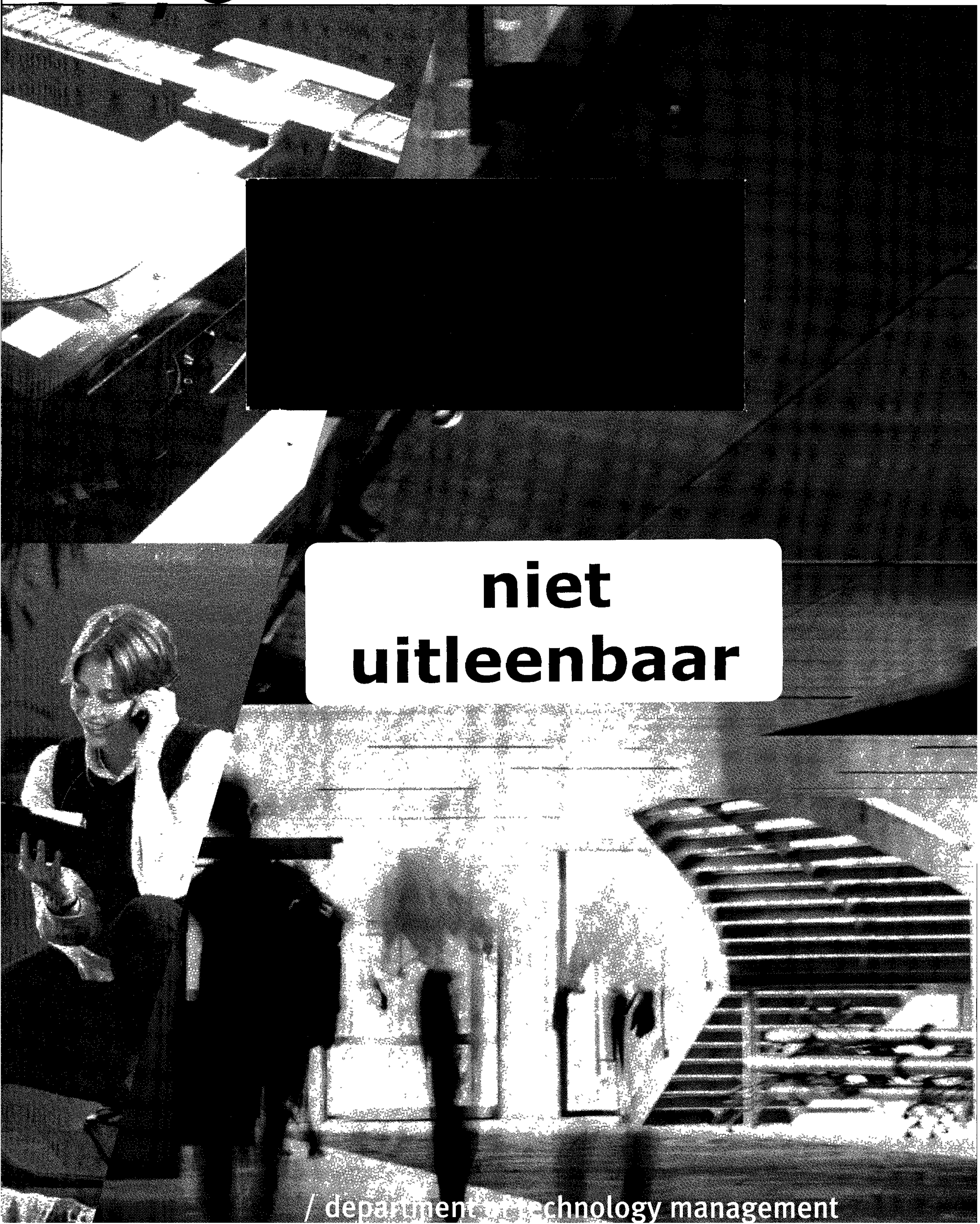

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Preface

This thesis was written as a part of my graduation project for the Human-Technology Interaction masters course at the Eindhoven University of Technology. The project was conducted at DAF Trucks nv in Eindhoven at the department of Product Development. As I have developed interest for the automotive field, I searched for an graduation project related to this. With this project at DAF Trucks I had found what I was interested in, making it especially interesting for me to conduct this study. With the conclusion of this thesis, I have had a very enjoyable and educational time both at DAF Trucks, learning practical aspects regarding trucks and the way they are engineered, as well as at the Eindhoven University of Technology increasing my theoretical knowledge.

Many people supported me in different ways during the eight months of this project. First of all, I would like to thank the team of supervisors for their support and advice, from DAF Trucks ir. Marco Snel, and from the Eindhoven University of Technology dr. Dik Hermes and prof. dr. Don Bouwhuis. My thanks go also to the people at the Technical Analysis group and other colleagues at DAF trucks for their help gaining insight into trucks and into the various aspects of truck driving, their hospitality and the nice time I had over there. Further, I had great help with recording and measuring sounds from Sander Custers.

I would like to thank my fellow students also, both at DAF trucks as well as at the university, for their support and pleasant time spent. And finally, I owe a lot to my parents, for their support and encouragements until the very end of all studies I finished. Again, many thanks to everyone.

Merijn Keser

Summary

Within the modern truck cabin, ever more devices are available supporting the driver with his tasks. Not only with truck driving itself, but also with all kinds of other tasks and providing entertainment, too. With this development, sound is becoming a more often used means, besides the visual modality, to provide information. Some examples of equipment using sound are cell phones, navigation equipment and warning sounds for adaptive cruise control or collision avoidance systems. Although many of these devices are designed for supporting the driver, there are many risks involved that can result in achieving opposite effects.

For a good human-machine interface, of which sound is a part, it is important to predict the effect it has on the truck driver. To predict this it is important to evaluate the tasks a truck driver performs. These tasks can be categorized regarding relevance to the driving task. This results in a *primary driving relevant task* that exists of forward visual tracking and road hazard monitoring. Further, there are *secondary driving relevant tasks*, like reading road signs, or determining direction, obtaining information needed to drive and to find the correct route. The third category consists of *driving irrelevant tasks*, all other possible tasks a driver could carry out while driving, like listening to music, or a making telephone conversation. For successful performance of a task, the operator needs to have sufficient Situation Awareness (SA). Thus, based on the tasks a truck driver has to perform as described, it could be said that task specific SA is needed:

- primary driving relevant SA;
- secondary driving relevant SA;
- driving irrelevant SA.

It is natural that primary driving relevant SA is most important, and should always be sufficient for safe driving. Nevertheless, the driver's resources to obtain sufficient SA are limited. This indicates the importance of a good interface design, which should provide the right information, at the right time, in the right form. People are capable of processing information in different modalities at the same time more efficiently compared to information in a single modality. This, and the fact that "auditory displays are omni-present and omni-directional" (Ho, 2006), are the main reasons why auditory information can be a useful tool to provide a truck driver with information. This aspect, however, can be both advantageous as well as disadvantageous: an auditory collision warning should attract a great deal of attention, no matter what. Driving unrelated auditory displays, however, can disturb the driving task by requesting attention from the driver; a cell phone conversation, for example, has this effect.

An inventory of truck cabin equipment using sound and possible future devices to be added showed a significant rise in the number of sounds that inform the driver. It is important, especially for equipment that provides primary driving relevant information, like collision and lane departure warning systems, that this information is instantly understood by the truck driver, as an instant response is needed. Knowledge, based on experience with auditory warning signals in, amongst others, airplanes and hospital wards, provides several recommendations to implement sounds in an ergonomically correct way. First of all, it is recommended to use less than six auditory warning signals; thus keeping the number of signals learnable. Further, the design of the sounds used is important. The sound should be appropriate to the message it communicates, for instance by having the correct perceived urgency and coming from the right direction. Further, measures should be taken to limit the number of sounds audible at one time, thus preventing one sound masking the other, and improving

perception, recognition speed, and raising response accuracy. This can be achieved by connecting the radio mute function to other devices that use sound, and by sequential prioritization between sounds.

An experiment was designed to study possible negative consequences stemming from a large number of signals becoming audible simultaneously. The experimental design also took possible solutions into consideration in the form of radio mute and prioritization between signals. SA is generally recognized as "a critical and often elusive foundation for good decision making" (Endsley, 1998), and was used as a criterion to judge the effect of the different sound conditions. Participants who sat in a truck cabin were asked to watch and hear different traffic situations that were presented on a large screen in front of the truck. After each traffic situation, SAGAT (objective SA) and SART (subjective SA) questionnaires were used to measure participants' SA regarding the situation they experienced. This way, a one-signal condition was compared with a multiple signal condition and with a condition where sound management was implemented in the form of radio mute and prioritization between signals. Less important signals were suppressed for more important signals according to the three task types discussed above. This measure is thus aimed at improving primary driving relevant SA.

Overall objective SA consists of components regarding the traffic situation that was visible, and the sounds, related and unrelated to driving, that were heard. Analysis revealed a significant deterioration of overall objective SA in the multiple signal condition and mute/prioritization condition compared to the one signal condition. However, as overall SA consists of different components, a more detailed analysis can be done. Analogue to the task categorization discussed above, SA regarding primary driving relevant auditory signals was analyzed. Results showed a clearly different pattern from that found with overall SA. A significant improvement was shown for the prioritization/mute condition in comparison with the multiple signal condition. SA reached a similar level as measured in the one signal condition. This effect shows that implementing mute and prioritization, and limiting the number of sounds audible at one time, is an effective measure for retaining primary driving relevant SA. This way, driver's response in hazardous situations could improve by better signal detection and accurate recognition. The experimental method that was used looks promising as a cheap and fast way of investigating different interface principles in comparison to methods using vehicle simulators or on-the-road experiments.

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1 Introduction

A truck driver has more and more devices available supporting him in his tasks, not only with truck driving itself, but also with all kinds of other tasks, such as handling the radio, the telephone, or paying toll. With this development, sound becomes used more often as a means to provide information and entertainment. Some examples of equipment using sound are phones, a citizen band radio, a navigation system and all kinds of warning sounds. In spite of the fact that all these devices are designed for supporting the driver in his tasks, there are many risks involved resulting in the opposite. Though originating from another profession, flying an aeroplane, the following extract from an interview shows the risks attached to the presence of a large number of displays providing information: "I was flying a Jetstream at night when my peaceful reverie was shattered by the stall audio warning, the stick shaker, and several warning lights. The effect was exactly what was NOT intended; I was frightened numb for several seconds and drawn off instruments trying to work out how to cancel the audio/visual assault rather than taking what should be instinctive actions. The combined assault is so loud and bright that it is impossible to talk to the other crew member and action is invariably taken to cancel the cacophony before getting on with the actual problem" (Patterson, 1990, p. 37). Besides the risk of non-intended reactions, as the pilot described, it is also possible that annoyance or aggravation could arise because of a continuous onslaught of signals. Implications like these raise the question whether existing and future devices using sound within a truck need some form of sound management to achieve an optimal interaction between the truck driver, the driving interface, and other technology available in the truck cabin.

A quick search on the internet showed that the term "sound management" is mostly used associated with environmental noise, for instance from airports, and ways of limiting that. It is a way of providing the best possible residential conditions near the airport, without limiting the functioning of the airport. In a way this is analogue to the situation in a truck. The truck driver should not be annoyed or overloaded with auditory input. The difference with sound management for airports is, however, that many sounds within the truck cabin are used specifically to provide information to the driver. The sound management system has to support the driver in such a way that he can respond accurately to these sounds from the various in-cabin devices. The following questions arise:

1. How should sound be used as part of the human-machine interface in supporting the truck driver?
   - Which properties are important for (warning-) sounds?
   - How do different sounds interact?
   - How do others, like the aircraft industry, hospitals, the automotive and truck industry, deal with this subject?
2. Which method is best suitable to compare different sound management concepts?

The general objective of this project is: To develop guidelines for the use of sound as a means supporting the truck driver by providing information regarding his driving tasks, thus improving usability and providing higher safety for the truck driver and other traffic participants. In short: How to use sounds as supportive as possible for the truck driver?

For his graduation project, De Jong (2005) conducted a study regarding Driver Assistance Systems which he used to develop guidelines for the human machine interface of a truck. Regarding auditory signals, De Jong developed a program for designing warning signals, and warning signal design recommendations. Using the design method by Patterson (Wickens et al, 1998), a number of warning signals were designed. Overall perceived urgency was investigated, as was the signals' suitability for the different warning systems. The research resulted in guidelines regarding the complete human machine interface, including information about the use of auditory signals (De Jong, 2005). His focus was on the design of these signals. One of his recommendations is to use less than six tonal warning signals. Furthermore, the signals should be well audible and should be acceptable for the driver. The driver should be able to adjust the properties of signals, and should be able to turn off audio except when it is used for warning signals. Finally, the occurrence of false alarms should be minimized. The field of interaction between different sounds, however, still remains open for study, and is the scope of the current report.

This thesis consists of a theoretical part first, followed by an overview of current and future developments regarding sound within a truck cabin, and finishes with the discussion of an experiment. The second chapter of this thesis discusses theory regarding the task of truck driving. With that, the concept of situation awareness (SA) is introduced, and how sound plays a role within that concept. The third chapter discusses factors important when sound is used; how to design sounds that are sufficiently audible and how to design sounds for good SA. Sounds present in trucks today, as well as future developments, are discussed in chapter four; literature is used to formulate some conclusions based on the expectations of future developments. Some of these conclusions, regarding the effects of multiple signals on SA and of automatic volume control, were tested in two experiments, described in the final chapter.

2 The driving task

Sound is one of the environmental factors, like visual or tactile information, influencing a user in his task of operating a device, in this case a truck. From a users' viewpoint, environment means both the system that the user is operating, and the environment in which the system is located or moves through. Sound can provide information regarding the task, truck driving, for instance by providing navigation messages. On the other hand, there are sounds that are irrelevant for the driving tasks, for instance the radio or a cellular phone. When sound is used as a means to provide information, it is important to know how people perceive and respond to sound. Thus, psychological mechanisms that can predict the effect sound has on a system user, in this case the truck driver are important to consider. Besides interaction between sound and the rest of the environment, sounds could also interact with each other. These effects need to be studied to determine the need for sound management.

The following example shows the possible catastrophic consequences of problems stemming from interaction between several environmental and user factors. Even aircraft pilots sometimes fail to understand the state of the plane in its environment, or the state of internal systems, despite extensive training programmes as the KLM versus PanAm Tenerife crash shows, costing more than 500 lives (Wickens, Gordon & Liu, 1998). The KLM pilot received instructions from the air traffic controller: "Okay, stand by for take off and I will call." At the time, weather conditions were deteriorating, visibility becoming poorer. Adding to the KLM pilot wanting to take off while it was still possible, radio quality was less than perfect. Apparently he just heard "Okay... take off.", which resulted in a disastrous collision with the PanAm aircraft. A whole range of examples (Patterson, 1990; Wickens, Gordon & Liu, 1998; Endsley, Bolté & Jones, 2003) is available indicating pilots loosing understanding of the system or environmental state. In other areas of profession, like the medical world, similar problems were found. Personnel did not know which problem to attend to first, or gave wrong responses to auditory signals (Edworthy & Adams, 1996). Although it seems that this kind of data is not so extensively available with respect to the automotive sector, it is highly likely that, because of task similarities, like navigating through the world and multi-tasking, that to some extent similar problems can arise in the field of driver-vehicle interaction.

To provide some insight into the advantages and function of auditory information presentation within truck driving, the tasks that a driver carries out, and the driver's resources have to be kept in mind. Traffic situations can vary enormously from low intensity to extremely intense. Ideally, driver attention and response capabilities should be sufficient to handle all situations, but since there is a maximum amount of workload for humans this is not possible. The same goes for attention, only a part of all received information is held in sensory memory: one subject asking attention goes at the cost of attention to another subject. Depending on the situation a person can focus attention or divide attention. Dividing attention, like driving a car and making a phone call at the same time, is called time-sharing. It can be achieved by attending to both tasks at once, or by switching rapidly between them. According to ISO (2004) the driving task is composed of three categories of activity which relate to each other:

- vehicle control;
- navigation;
- collision avoidance.

Regardless of driving conditions, the driver continuously has to multi-task carrying out the three activities stated above. Many of the tasks that need to be carried out become automated with growing driver experience (ISO, 2005). Another way to categorize the tasks a truck driver has to perform can be done in a similar way as Wickens (1998), shown in figure 1, who divided tasks to be carried out while driving into a primary task and a number of secondary tasks. Driving exists primarily of a tracking and road hazard monitoring forward vision task. Secondary tasks are all other activities that are carried out while driving, from road side monitoring to listening to the radio. However, these secondary tasks consist of two distinct categories, tasks that are, like the primary task, driving related, and tasks completely irrelevant for driving although performed while driving. Therefore, I propose to divide the secondary tasks into secondary driving relevant tasks, and driving irrelevant tasks. The secondary driving relevant tasks, like reading road signs, can take resources away from the primary driving task, but they are still necessary for sufficient performance on the driving task; to determine direction, maintain speed limits, or perceiving information otherwise needed to drive and navigate. The driving irrelevant tasks consist of all other possible tasks a driver could carry out while driving, such as listening to music or a telephone conversation. To summarize, I propose to divide the tasks performed while driving into:

- primary driving relevant tasks;
- secondary driving relevant tasks;
- driving irrelevant tasks.

All these tasks compete for the limited resources a human has for carrying them out.

According to Wickens' (1998) multiple resource theory a persons resources are better used if multiple sensory modalities are used. This way it becomes easier to provide sufficient attention to the tasks a person is fulfilling. For instance, it was found that people are better able to drive a vehicle when route guidance is presented by vocal messages additional to visual presentation, instead of visual presentation only. The visual tasks request more resources when route guidance is presented by visual means only and causes speed control to suffer and increases lane deviation (Dingus, 1996). This also means that the driver's workload is lower when vocal route guidance is used instead of a display in the form of an in-vehicle screen or a road map. The example shows the benefit and goal of implementing in-vehicle auditory displays: driving used to be mainly a visual input and manual response task. Now an extra modality is used, making it easier to perceive and interpret the messages.

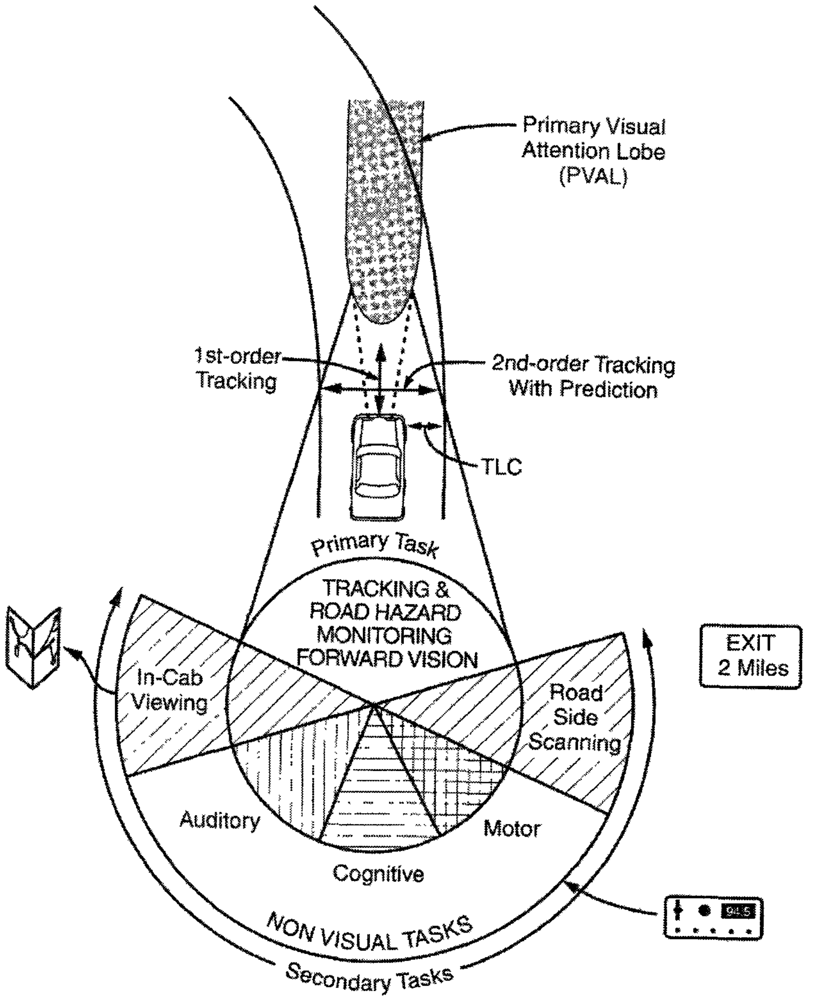

Figure 1. Deviation of human resources over driving tasks (Wickens, 1998)

2.1 Situation awareness

The most commonly used formal definition of SA is from Endsley (1988): "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." This does not mean that it is necessary to know everything, which is even not possible as people have limited means to process sensory input. It is necessary, however, to have sufficient relevant knowledge for that specific task. Schematically, the creation of SA is represented in figure 2. The system operator perceives information from the environment, thus creating awareness of the situation. The topic of SA became important because it was found that people failed to keep in mind the state of the world under high workload situations. For successful task performance it is necessary to evaluate the situation accurately (Endsley, 1988; Wickens, 1998): the user of a system needs sufficient Situation Awareness (SA) for successful system operation. It is clear that the risk of losing SA rises with growth of the number of devices a user has to operate, as human resources to perceive, think and operate are limited. Another risk for losing SA lies within automation, causing the human to become a system monitor instead of a task performer. Further important factors are stress, workload and task complexity. Hence, independent of the users' ability to detect failures, it will be less likely that their intervention is correct and appropriate if they do not fully understand the system's state. Effects on SA can come (among others) from changes in the quality and form of feedback provided by the human machine interface.

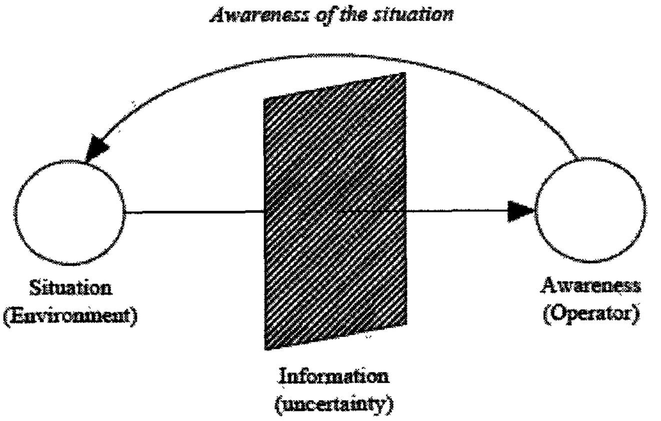

Figure 2. A systems framework for mediated SA, from Kirlik and Strauss (2003).

As can be derived from the formal definition of SA mentioned earlier, there are three levels of SA:

- 1SA: Perceiving information, for instance the state of on-board systems, location of the vehicle, environmental properties and location of other traffic participants.
- 2SA: Creating a mental picture of the situation: comprehension of the situation and its current significance and understanding of the situation (Kirlik & Strauss, 2003).
- 3SA: Predicting of future state, e.g. "I can drive another 100 km before I need gas".

To create sufficient higher level SA, it is necessary to have sufficient SA on the lower levels: the right information has to be perceived to create an accurate image of a situation, which subsequently is necessary to make accurate predictions of the future state of the situation. Thus, to realise good SA, it is necessary to provide the right information, in the right form, at the right time (Wickens, 1998). Providing as much information as possible is useless, since humans cannot perceive an endless amount of stimuli. Thus, developers have to carefully weigh what information to provide and what not. Although the difference is small, studies showed that response to visual stimuli is mostly faster (Selcon, 2000) compared to response to auditory signals. Despite of this, the usage of auditory signals has undeniable advantages for the transmission of warning information due to its property that it is independent of the driver's head position or locus of visual attention (Doll, 1986). This means auditory displays are omni-present and omni-directional (Wei Ling Ho, 2006), whereas for visual signals there has to be visual contact with the display. During a driving task, the main visual attention is located through the windscreen, the rear view mirrors, and somewhat less, to the dashboard (Wickens, 1998). This leads in practice to faster detection and thus response times for auditory signals. These aspects of using sound, however, can also be disadvantageous. For example, it was found that even just receiving auditory messages can influence driving performance (Green, 2000). Traffic messages like "I-94 eastbound at Southfield freeway, continuing construction, right lane blocked, three mile backup" made participants' speed variance increase. This indicates that a verbal message attracts a great deal of attention, in this case resulting in a poorer driving performance. This is what is called the auditory pre-emption effect: auditory information attracts more attention than visual information (Seppelt & Wickens, 2003). This effect probably originates from the fact that humans are more experienced and capable in filtering visual information compared to auditory information (Wickens, 2002).

For obtaining SA needed for driving a car safely, perception and cognition of stimuli that are important for the "primary driving relevant tasks" is needed. For instance, checking a map or hearing the cell phone ring do raise overall SA, but not SA needed for successful performance on the "primary driving relevant tasks". On the other hand, viewing the road ahead or hearing a collision warning can raise SA for successful performance. Based on the tasks a truck driver has to perform as described, it could be said that task specific SA is needed:

- primary driving relevant SA;
- secondary driving relevant SA;
- driving irrelevant SA.

A conceptual map of SA within the trajectory of perception, interpretation or cognition and response is shown in figure 3. Situation Awareness and the human response do not only result from the state of the environment, but personal factors also play a role in limiting or raising perceptual, cognitive and response resources.

Sound can be used as a means to increase SA, warning signals are a typical example of this, but navigation messages are also means to raise SA. However, it is not enough that the user knows that "something is wrong" at a 1SA level. Especially for warning signals it is important to achieve a quick interpretation and comprehension at the 2SA level. Auditory warning signals should provide information that would otherwise remain unnoticed, or information about rapid changing circumstances, thus supporting good SA.

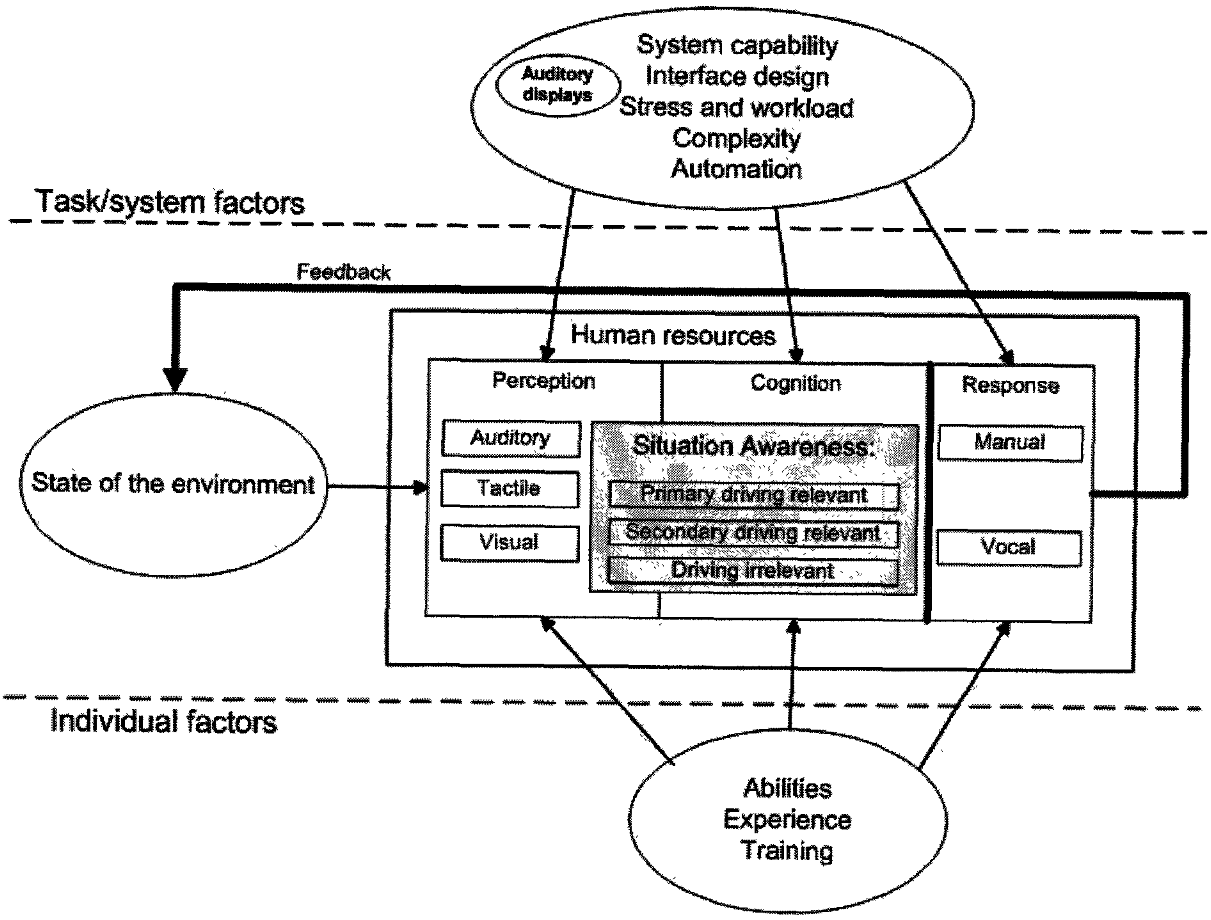

Figure 3. Human resources and SA (based on figure 4, in Denford et al., 2004).

2.2 Response to signals

With the introduction of signals, auditory or visual, giving information on primary driving relevant SA, it becomes important to predict the response to such a signal. Quick and accurate responses by the driver are needed at this level, certainly in case of a high collision risk, for example. How auditory warning signals specifically should be designed will be discussed in the following chapter. Besides signal design, some more factors are important to achieve the most accurate and quick response to a signal.

Wickens (1998) discusses that average "time to react", meaning detection, understanding, and responding to a signal, is 2.5 s for the mean driver, and varies between 2 and 4 s. This was found in actual on-the-road measurements. For design purposes it is advised to use a range of 3 to 4 s. These times are significantly longer compared to results found in detection tasks for psychological laboratory experiments. Thus, these laboratory experiments can serve as relative comparisons between different concepts, but the response times cannot be used as an estimate of the response in a practical situation.

As explained earlier, in case of a hazardous situation, auditory displays can be used as a means to limit the "detection" time by being omni-present and omni-directional. Because of limited human resources, however, other information, both auditory and visual, can lengthen the "time to react" by enlarging the workload. Workload rises because the perceptual resources are more extensively used, but also because decision making becomes more complex; first by deciding which information is most important to respond to, second by deciding which is the appropriate responsive action to take. Another example of an unwanted response, this time in the form of a startle reaction, was discussed in the introduction of this report, the pilot being "frightened numb" by the large number of warning signals that were presented. Al these possible risks indicate that presenting only the most important information is crucial, especially in hazardous situations. Thus, the more alarms occurring in rapid or concurrent sequences, the less likely it is that they are detected and processed properly (Endsley, Bolté & Jones, 2003), signals can become camouflaged or masked by other sounds. Prioritization between sounds is a means to prevent that the gains of implementing warning sounds are cancelled by signals interfering with each other. With regard to auditory signal design, this can be done by manipulating a signal's perceived urgency. To prevent masking, the designer has to take other sounds that are audible concurrent to the signal that is designed into account. These design properties are discussed in chapter 3. A further step is to prevent the possibility of two signals becoming audible at the same time: recommendations (ISO, 2005) advise to display the most important message first, suppressing lower priority messages. Doll (1986) has summarized some options to deal with priority:

- automatic prioritization and sequential presentation of signals;
- maximizing signal distinctiveness;
- varying the apparent direction from which the competing signals originate.

The only measure that limits sensory input is by automatic prioritization and sequential presentation of signals. Furthermore, directional information should above all provide information concerning the source of the hazard or point to a location where more information concerning the hazard can be found.

Systems having more auditory signals at disposal can lead to events where different signals follow each other in a short period of time. Depending on the time between signals, Wiese and Lee (2004) found that the signals can either improve or deteriorate response times. A high priority collision warning, preceded 300 ms by a low priority e-mail notification, resulted in a longer (240 ms) response times compared with the collision warning presented alone. In a second experiment however, in which the time between the signals was increased to 1000 ms, better response performance was measured. The first signal made participants raise their alertness, though it interfered with a second signal if it was presented too close to it. The authors give the advice to delay low urgency messages like an email alert if collision warning systems start to detect the possibility of an oncoming collision. This way an extra alarm level is added, that makes sure less important signals do not become audible. Caution has to be taken, nevertheless, with a measure like this: a trade off has to be made. Delaying all lower priority messages or disrupting phone calls every time a warning system starts to detect a collision risk could raise annoyance in case the user cannot perceive the cause of the disruption, and the possible risk of a collision is still limited if the actual collision warning is not sounding yet.

Another factor needs to be mentioned, having influence on response to signals: false warnings. Many false warning signals make the driver becoming cautioned towards the system, it also leads to annoyance and more incorrect responses to a signal (Wei Ling Ho, 2006; Bliss, 2000), and to a slower response. Ho & Spence found that response speed deteriorated by 200 ms when the number of false warnings was higher. A possibility to limit annoyance is to lower the perceived urgency of a signal that is prone to sound at relatively many false occurrences: a trade off has to be made between perceived urgency and annoyance to reach an optimal response (Wiese and Lee, 2004), and thus prevent that people are going to ignore the signal, or shut the device off.

2.3 Summary

According to theory, the driver will need to provide more attention from his limited resources to process every bit of extra information, deciding on the information's importance, and deciding which response is appropriate. Providing auditory information leads, according to Multiple Resources Theory (Wickens, 1998), to a relatively more appropriate response. Sound can be used to relieve the visual resources which are extensively used during driving. This is typical what is achieved by navigation aids that use speech messages; it is not needed anymore to look at a map or a display.

People are capable of processing information in different modalities at the same time more efficiently compared to information in a single modality. This, and the fact that "auditory displays are omni-present and omni-directional" (Ho, 2006), are the main reasons why auditory information can be a useful tool to provide system users with information. The auditory pre-emption effect however, shows that this aspect can be both advantageous and disadvantageous (Seppelt & Wickens, 2003). A collision warning should attract a great deal of attention, no matter what. Driving unrelated auditory displays, however, can disturb the driving task by requesting attention from the driver. It can be concluded that providing as much information as possible is useless, and achieves even counter productive results. First of all, a careful analysis is needed to decide on the necessity to introduce a new signal to an interface. Another solution for this problem is, besides a good auditory signal design that is discussed in the next chapter, to prioritize between sounds. This way, the information that needs to be processed by the system operator is limited.

3 Sound

In this chapter, some basic principles regarding human sound perception will be discussed, before elaborating on the different sounds that can be found within a truck.

3.1 Perception of sound

The nervous system humans, and most other mammals, have for detecting acoustic energy consists of ears, auditory nerves, and parts of the brain. The most visible part of the system is the pinna, or outer ear, which collects and modifies sound waves. The sound waves are then channelled down through the ear canal, a 25 mm long tube, 7 mm in diameter. This tube has a resonant frequency around 3000 Hz, causing sounds in that range to be amplified by several decibels. The sound waves are transmitted through the middle and inner ear before they are transformed into electrical currents travelling to the brain. The human auditory system is not "designed" to preserve absolute frequency or intensity of sound sources, rather, the system detects differences in sounds. Loudness is a very familiar concept related to the intensity of sound. It is important, however, to note that it is a subjective impression; most people would agree on whether one sound is louder than the other, but there is no way to compare each others' loudness impressions directly. Psychologists have worked around this limitation by using methods like loudness matching, adjusting two sounds until they are perceived as equally loud. Another method is magnitude estimation by assigning numbers to sounds. As with loudness, pitch is a subjective experience of ordering sounds, but this time from high to low. This perceptual property of pitch is associated with periodicity. The fundamental frequency or first harmonic is the lowest frequency mode of a periodic sound. Harmonics or overtones are integer multiples of the fundamental frequency. If one harmonic, or even the first harmonic, is deleted from a sound its pitch is still perceived as being the same. Another example to show that pitch is not necessarily the same as frequency: a 1000 Hz tone is perceived as roughly half way between 4000 Hz and a very low frequency tone.

Directional information is an important aspect in perceiving sounds, as it draws attention towards that direction. The term azimuth is used for specifying the horizontal direction of a sound relative to the head, the term elevation for specifying vertical direction. The discrimination of direction resolution of sound direction depends on the location relative to the head where it is coming from. Direction in the azimuth is more accurately discriminated from the side than from the front or rear. Important cues used for discrimination of direction are interaural time differences and interaural intensity differences. Some other cues are movement of the sound producing object or the listener, loudness changes or echoes. It should be noted, that higher frequency sounds are overall more difficult to localize (Patterson, 1990), especially when composed of only one or two components.

The phenomenon of auditory masking is a very familiar one: hearing a weak sound becomes harder whenever you hear background noise: this principle causes people to turn up the radio volume in their car, or truck for this matter, when they turn up a highway. Within the bandwidth and a certain energy level of the background noise, another sound is more difficult to detect. Masking of a sound is likely when they are close in frequency and have approximately the same level of intensity (Sekuler & Blake, 2002). However, if sounds have a similar intensity level, but are further apart in frequency, masking will be reduced and it is easier to detect the two tones. However, the masking effect is somewhat stronger on the higher frequency side of a masking tone. This effect is called upward spread of masking.

Context is an important factor in perceiving speech, which can be the topic of the conversation itself, or it could be another factor, like the movement of the lips of the person who speaks. Familiarity is also of importance: a song that is familiar is understood word for word under difficult hearing conditions, but this is not possible when you hear a song for the first time. The familiar song is understood because of top-down processing: the little information received is linked to information already known, filling in the information that was not received. With an unknown song this is not possible making it necessary to be clearly audible to perceive and understand it correctly. In this case, top-down processing supported correct performance, but it can also lead to misinterpretations, the brain making wrong assumptions. Other implications can be caused by the integration of information of multiple modalities. In a similar way as the so called Stroop effect (Selcon, 2000; ISO, 2005), an auditory display in combination with a visual display or visual event can lead to facilitation of correct responses if both modalities are congruent. If they are perceived as different or incongruent, they will interfere with the response (see false warnings). For instance, when the words "high" and "low" are presented with incongruent pitches, interference will occur leading to slower responses, and more mistakes in recognition.

A last subject regarding auditory perception that needs to be mentioned is hearing loss; the most common source of it being age. Especially for important auditory warning signals this factor has to be taken into account. For a 60 year old male, hearing loss at a frequency of 1kHz is around 10dB, at 4kHz it raises to 25dB (Wickens,1998). This shows the importance for a warning signal having sufficient components in the lower frequency range, where deterioration of hearing is less strong, and thus the chance for detecting a sound is larger.

3.2 In-truck sounds

Most scientific research on the use of audio focus on one type of device only, for instance on cellular phones, or auditory warning signals or on ways to limit background noise. For the purpose of maintaining a clear overview on all the different sound sources to be found in a truck, or motor vehicles in general, four categories (see table 1) are proposed with respect the sound type within the cabin environment. It has to be noted that the categories mentioned and their properties are somewhat ambiguous. Some people hardly use the radio, some auditory signals are presented every time the direction indicators are used, further, future devices using speech recognition could fall in both communication and auditory display categories. The continuous sounds are considered to be always present but they differ in intensity or frequency spectrum. For a short-range distribution truck the background noise differs a lot; the truck does a lot of accelerating and slowing down. For a long-range international-transport truck, this noise can be more uniform when driving long stretches of highway. The sounds of these different categories all influence each other; an example familiar to everyone is turning the radio volume up when you are driving onto a highway. And the other way around, when you notice the radio is playing extremely loud when you drive from the highway into a gas station.

Table 1. Sound categories.

Auditory source	*example*
Background noise	Engine noise
Entertainment and information	Radio
Communication	GSM/CB
Auditory displays	Navigation message, Collision warning

Most of the time, people will have their radio turned on, and while listening there are several auditory events that can interfere: a warning sound coming up, the phone ringing, or messages coming from the navigation system have to be interpreted. Besides these interaction effects with each other, as will be discussed more elaborate later in this report (for example, see chapter 3.3), it was found that even just receiving auditory messages like traffic messages, like mentioned in chapter 2.1, can influence driving performance (Green, 2000).

3.3 Background noise

The most obvious continuous or environmental sound is background noise; depending on the specific situation it will change, but it is always present. Background noise requires no response; the resources used by background noise are very low. Only unexpected changes could direct more attentional resources to it. Background noise is an important factor, however, because it can mask other sounds.

Background noise is an important, always present factor to be taken into account when developing devices that use sounds to convey a message. If the warning sound level is too low, it will remain undetected. If the warning sound level is too high it will be unpleasant, may induce a startle response, or can even be dangerous to the human hearing system. As an example regarding background noise levels, a Federal Highway Administration report (Green et al.,1995) summarized the influence of several factors on interior noise. Opening a window at 48 km/h showed an increase in background noise of 2 dB; this was 5 dB at a speed of 80 km/h. The usage of snow- or studded tires made the noise increase up to 8 dB. Driving on wet roads made noise increase by 3 dB. Finally the radio could increase the noise level up to 20 dB. It was found that aerodynamic and road/tire noise increased by 12 dB per doubling of the vehicle speed, and engine/drive train noise increased by 6dB per doubling of the vehicle speed. These results were found in old studies regarding model years 1970 to 1974 US cars. Although not up to date, it shows the multiple factors background noise can depend on.

A correct sound level for auditory messages to be audible over background noise can be established by first determining the background noise over the complete spectrum. Second, the auditory threshold has to be established which lies typically about 15 dB above the background noise. The auditory threshold is the sound level at which, under ideal listening conditions, an auditory signal is detected correctly for 50% of the cases. To be detected, the frequency components of a warning signal should have an intensity level 15-25 dB above the auditory threshold (Patterson, 1990; Edworthy, 1994; Antin, Lauretta & Wolf, 1991). Extensive methods were developed by Patterson and Laroche et al., as described by Edworthy and Adams (1996), for an exact determination of background noise level, the threshold level and the resulting range usable for auditory presentations. However, as a general rule of thumb, the 15 to 25 dB above masked threshold rule is sufficient for important warning signals that do not occur on a regular basis. Another method can be used that determines the auditory threshold in a more experimental way: Antin, Lauretta and Wolf (1991) have let participants detect auditory signals under certain driving conditions, e.g. 56 km/h and 89 km/h, during a simulated driving task by means of a computer game. The 95% detection level can than be measured, which can be used to determine the 50% detection level or the auditory threshold, using a cubic regression model. They found that the detection level in decibels above the masked threshold was significantly dependent on noise level. For a 56 km/h (49 dB) noise condition, the detection level was only 8.70 dB above the masked threshold, rising to 17.50 dB above masked threshold in the 89 km/h (62 dB) condition. This indicates that, to reach the detection criterion, the sound intensity of signals should not just be greater than the intensity of the background noise with a certain level. The difference between background noise intensity and signal intensity should be greater when background noise is louder.

Based on their findings concerning audibility of alarms in a hospital environment, Momtahan, Hétu and Tansley (1993) proposed to implement an automatic volume control to keep signals at audible levels without making them too loud. The automatic volume control samples ambient noise and automatically adjusts the warning signal to remain audible for environments where type and intensity of background noise changes. This could be applicable to road vehicles, too, since background noise is found to be highly variable. The advice to implement an automatic frequency specific intensity control can also be found in ISO guidelines regarding ergonomic aspects of transport information and control systems in road vehicles (ISO, 2005).

3.4 Entertainment and information devices

The most common example within the class of entertainment and information devices is, of course, the radio. It could almost be considered as a sort of background noise, as many truck drivers have it turned on continuously. Unlike the background noise, the radio sound can be dynamically manipulated, not only by the user but also by the product development team, for example in the form of an automatic radio mute. The human resources requested by entertainment and information devices can vary from a very low level, hardly higher than when listening to background noise, to a much higher level, e.g. getting immersed into the music or when listening to speech. Depending on the type of information that is listened to, a long term responses could be required, for instance, a reaction to traffic messages. Strikingly, research on the influence of radio listening on drivers is very limited. Some studies, however, were found with regard to audibility of auditory signals over radio noise (Antin, Lauretta & Wolf 1991), and some discussing the influence of music on drivers condition (Wiesenthal et al., 2000; Oron-Gilat & Shinar, 2000). The radio can also be used to present traffic messages; these are considered to be of a different category than radio noise in general and are explained more elaborate under "speech messages". As already mentioned, a study by Green (2000) showed that traffic messages can decrease driving performance as, for instance, speed variance is increased by such messages.

The study by Antin, Lauretta and Wolf (1991) already mentioned in the previous chapter, included also a "50 km/h and radio noise" condition, besides the "50 km/h" and "80 km/h" conditions. Preferences for warning signal intensity levels were also studied. They found that the preferred warning signal intensity level was about 10 dB above the 95% detection criterion with background noise produced by a car driving 56 km/h; for an 89 km/h driving noise condition this preference was reduced to 6 dB above the 95% detection criterion. In the radio condition combined with 56 km/h driving noise, participants were allowed to self set a radio channel and volume. Strikingly, in this condition the preferred intensity level was exactly similar to the 95% detection level. These findings suggest that participants preferred an intensity level for auditory warnings that does not interfere too much with the radio broadcast. It was also noted that variability in the radio condition was high compared with the other conditions in their experiment; indicating the difficulty of dealing with a "background noise" like the radio when there is a need to present auditory signals.

With regard to music, it was found that it reduces stress while driving (Wiesenthal et al., 2000). Participants were placed in a no music and a music condition; in the latter they were allowed to select their favourite music for listening to while driving. The music group showed a significant reduction in stress in higher stressful situations, a high traffic congestion level. This effect was supported by research in other than automotive fields. Depending on the circumstances, music can also lower driver aggression (Wiesenthal, 2003). Finally, it was found in several studies that truck drivers (Oron-Gilat & Shinar, 2000; Van den Berg & Landström, 2006) use the radio as a countermeasure for sleepiness by turning it on, or by turning the volume up.

3.5 Communication devices

Communication devices require of people to use variable resources. The modalities used are sound and vocal response, these modalities should, according to Multiple Resource Theory, cause low interference with a driving task which consists mainly of visual input and physical response. Depending on the topic of conversation, a substantial workload could arise on the cognitive process: when, for instance, having an argument. Nowadays, it is widely known that making telephone calls deteriorates driving performance, also when using a hands-free device (e.g., Green, 2000; Beede & Kass, 2006). Making phone calls and using a citizen band radio involve a listening and responding task, besides some manual tasks. Depending on the topic of conversation, this can be more difficult than listening to navigation messages. In the last case there are only two options: comply with the systems advice, or do not comply. In a phone call, however, the response possibilities are unlimited, and the problems larger thus requesting a lot more attention. To limit workload on the driver, hands-free kits were developed as a means to limit the manual tasks. This is, however, only a partial solution as the conversation itself can be enormously attention demanding (Tijerina, 2000). The usage of the citizen band radio, a device typical found in trucks, while driving is a comparable task to making phone calls. This means that it has in general similar risks and implications. It is difficult to develop measures besides the hands-free device to limit the risks while calling.

A future development likely to be used for in-vehicle computers is speech based interaction in the form of Automatic Speech Recognition (ASR) and text-to-speech technology which seems very logic with multiple resource theory in mind. Some implications arise, however, like those found with (hands-free) cellular phones which have shown that they can increase driver's response time substantially (Lee et al., 2001). Fussel et al. (2002) studied the implementation of voice dialling, together with auditory presentation of the phone book and found similar results: although participants looked less on the telephone when speech was used, driving performance seemed to be similarly affected. An implication of this is that a substantial percentage of people preferred to do a visual search above hearing a list: it was found that for a hotel call task while driving only 40% to 63%, depending on task difficulty, preferred to hear the information. Lee et al. (2001) used an in-vehicle e-mail system in a simulator environment for their experiment and showed a 30% increase in reaction time compared to a no-email condition and a large increase in subjective workload. Although reaction time did not increase when system complexity rise, subjective workload did increase. Although the risks of using cellular phones in traffic were also found in crash statistics (Fussel et al., 2002), the use of ASR and text-to-speech technology has been mainly in the field of experimental simulator studies. It is likely that participants perceive the risks lower in a simulator environment compared to the real world, and thus pay more attention to the e-mail system. The fact that people have very limited experience with these kinds of devices could also direct more attentional resources away from driving and towards the device. Nevertheless, studies like these show that speech based interfaces are likely to use the same cognitive resources as are used for driving.

3.6 Auditory displays

Auditory displays are used to support the driver in his primary or secondary tasks by being omni present and omni directional in contrast to visual displays. Otherwise their function is the same: to inform the driver on system state, or other events. Furthermore, according to multiple resource theory, they provide a means to distribute information over multiple senses. Auditory displays request a specific predefined response in the form of a manual reaction or to note an event or system state. Cognitive load caused by an auditory display can vary due to display familiarity and response complexity. Three categories of signals to be used for auditory displays can be distinguished:

- earcons or tonal signals;
- auditory icons;
- speech messages.

Earcons exist of abstract series of synthetic tones with a well defined rhythm, having no intrinsic meaning; the system user has to learn for each signal what it means. Familiar examples of earcons are the sounds a telephone produces to indicate that the number is calling, or is busy. It is, however, necessary to design earcons in such a way that it is applicable to the information it presents: the perceived urgency of the signal, discussed later to a greater extent, should match the urgency of the situation it communicates. The second class of signals, auditory icons, do have a clear meaning connected to the message they communicate. An example of this type is tyre skidding sound used as a collision warning. The final category of speech also has a clear meaning, that is, if the message is understood in the same way it was meant and if audibility is sufficient. The three main categories will be discussed more elaborate in the next paragraphs. Six basic properties are important to keep in mind when designing or applying auditory signals:

- Identification: A signal has to be easy to identify, so the sounds have to be easily learnable. When auditory icons are used, the issue of learnability is much less important because it is highly likely that the meaning of the sound is already known to the system user.
- Discriminability: Clearly different sounds have to be implemented, so that mistaking one for the other will be prevented, especially when immediate action is required.
- Urgency: The perceived urgency of auditory signals has to match with the urgency of the cause.
- Localizability (how far, speed changes, direction): For quick localization of the problem, the auditory signal has to be designed in such a way that it can be localized easily. Both signal properties and loudspeaker location are important to achieve this.
- Annoyance (discussed in chapter 2.2).
- Interference (discussed in chapter 2.2).

More specific information regarding these basic properties, the different types of signals and signal design can be found in appendix A.

Before discussing general properties regarding the three types of auditory signals, another variant has to be mentioned, the gradual or incremental signal (Bellotti, 2002). Designing a signal this way, it becomes less an ON/OFF or binary signal. To create such a warning, intensity or temporal signal properties can be varied. The latter is often seen with parking aid systems, the signal's tempo becoming faster when the vehicle comes closer to an object. This way, the alarm is more congruent to the situation it informs about. This congruency effect could also be applicable with other collision warning systems. It appears however that this field is not extensively studied yet for other applications. Although advantages look promising, relatively little research is done on this field, making it interesting for future research.

3.6.1 Earcons or tonal signals

The use of earcons has specific implications that need to be taken into account when designing them. These implications are primary related to the fact that an earcon has no intrinsic meaning. As ISO (2005) guidelines state, an earcon is intended to elicit a specific drivers' behaviour. This intended behaviour should be explicitly formulated by the designer; this comprehensibility should be measured to ensure that the desired response is achieved. A procedure regarding testing of compliance is specified in ISO 15006 (2005), additionally some general recommendations for signal design for appropriate urgency are provided, which are based on findings discussed more elaborately in appendix A:

- Short-term message: Sweeping sounds, bursts of sounds, alternating tone pitch.
- Medium-term message: Patterns of segments with constant pitch, the shortest at least 0.3 s.
- Long-term message: Two-times chimes, high-low recurrent followed by a verbal message or visual display.

Some specific implications to deal with earcons are discussed in appendix A, including an example of a successful designed sound interface.

Studying auditory warning signal preferences, De Jong (2005) found that participants preferred claxon-like signals for critical warnings as a collision warning, and did not prefer those sounds for less-critical systems as Active Cruise Control (ACC). This could be caused by an association of a claxon sound to a high emergency event, in a similar way as sirens of emergency vehicles raising alertness. Previous experiences and perceived signal urgency are important factors to consider when designing an earcon or tonal signal.

3.6.2 Auditory icons

Auditory icons are by their nature representational and thus easier to associate with a specific situation. Because of these natural representational properties, auditory icons fall in the category of ecological displays. Tire squeaking sounds were used in experiments as a collision warning, resulting in faster reaction times compared to earcons as found by McKeown (2002) in an experimental setup. In his masters-thesis, Belz (1997) described similar results; the auditory icons used as a collision warning resulted in significantly faster brake response times. However, his work also indicated that participants regarded them as being "not serious" as a warning. Work by De Jong (2005) confirmed this. Besides the lack of seriousness, another problem could arise due to cultural differences: the sound connected to an event could differ between cultures or countries. An example are rumbling strips, they sound different in the Netherlands compared to Germany. This calls for the need to test sounds for their meaning in several countries where the product is marketed.

De Jong (2005) also investigated natural associations between the different truck systems and (tonal) warning sounds belonging to them; these natural associations make a sound into an auditory icon. Except for the Lane Departure Warning signal, that was specifically designed as an auditory icon resembling rumbling strips no associations were found.

3.6.3 Speech messages

Although speech is considered to be easy to understand, it has some specific problems that need to be reckoned with: confusion between different communications, a bigger risk of masking, and mistakes in interpretation are some of them (Wickens, 1998).

The example discussed in chapter two, regarding the Tenerife crash, shows, besides masking, another problem regarding speech: bottom-up versus top-down processing. The less than perfect radio quality made it difficult for the pilot to perceive the message from the control tower the way it was intended, indicating problematic bottom-up processing. This may create a problem regarding top-down processing; the pilot heard what he wanted to hear. To support accurate top-down processing it is important to take into consideration that people perceive and interpret messages the way they expect to perceive them on basis of their experience (Wickens, 1989). A possible solution to this risk is to provide extra information, for instance by using a visual display that provides redundant information. Typical, this is implemented within navigation devices providing both speech messages and a visual display showing navigation information. Issues regarding navigation messages are discussed more elaborate in appendix A.

3.7 Summary

The field of auditory display design itself is relatively well investigated, especially with regard to auditory warning signals; extensive design guidelines have already been developed in the process showing how signal variables like intensity, frequency or rhythm influence perception of a signal. It was shown that perception of an auditory signal has to be as congruent as possible to the message it is meant to communicate. Three types of auditory displays exist; beside earcons, there are speech messages and auditory icons. Earcons have the disadvantage that they do not convey an intrinsic meaning, but have to be learned. This is no problem for speech messages, but it can lead to annoyance and distraction when a navigation message is misunderstood or not heard. Speech messages are considered normal to use with navigational devices. For other applications, however, earcons are more common, and according to literature more recommendable. One of the main arguments against the use of speech messages are the time that is needs to present a complete message, thus delaying a user response. Speech messages would also require language specific systems. Some guidelines with respect to speech are provided in ISO (2005). The last category of auditory signals, auditory icons, is under debate for highly urgent warnings. The main issue is the lack of seriousness for many situations considered to be connected to auditory icons. A final item to mention regarding warning signals is the incremental warning (Bellotti, 2002), capable of reducing the perceived occurrence of false alarms and providing a better analogy to certain events compared to the classic on/off warnings. Again, although the incremental warnings look promising, the amount of research in this field seems limited.

When a system of auditory warnings has to be developed, ISO guidelines for in-vehicle auditory presentation (ISO, 2004) should be used as a basis. These guidelines are very general, thus far from sufficient for developing a complete auditory in-vehicle system. Patterson has developed more specific guidelines with respect to warning signal design. The basic idea behind his methodology is a similar system to the colour coding that is often found on visual warning displays. The methodology was developed during the process of designing an auditory warning system for helicopters. Since then, the methodology is used in several other fields of application. Basis of the system is an analogy between the signals and their redundant visual displays of red, yellow, and green warning, and of information lights. With respect to auditory displays, the following main properties are important to keep in mind when designing them:

- identifiability;
- discriminability;
- urgency;
- localizability;
- annoyance;
- interference.

A topic hardly studied is automatic volume control. Without such a system, the risk rises that under high background noise intensity levels, a signals gets masked, resulting in detection difficulties by the system user. On the other hand, a signal could also be designed overly loud to ensure that it is audible under all conditions. Edworthy (1994) summarized the risks of having warnings that are too loud: with regard to (truck) driving, in the first place, they could lead to startle reactions preventing well considered actions and planning. Second, devices using too loud signals could be switched off by the user because of annoyance, thus losing the extra information the device could provide. Third, also because of annoyance and aversiveness, users could first try to turn off the warning signal before attending to the problem. A fourth consequence is the interruption of possible communications. ISO (2005) guidelines advice that the auditory message level should automatically adjust to the frequency spectrum of the background noise. In practice, this is difficult to achieve in a good way: to adjust correctly, the complete frequency spectrum should be dynamically measured and the signal constantly adapted. However, a rudimentary form of automatic volume control can be found in some navigational devices and radios. These systems adjust volume as a function of the engine Rounds Per Minute (RPM) and/or vehicle speed. Although sometimes implemented in these crude forms, research regarding effectiveness of such systems is lacking.

4 In-truck sound systems and drivers opinion

To obtain more insight into the usage of sound within trucks, the current situation has been studied to detect implications with research and to investigate where improvements can be made. To compare different principles, a benchmark was conducted with respect to the kind of sound systems truck manufacturers install in their products. Further, it was investigated what kind of aftermarket equipment could be installed, and what kind of nomadic devices (like cellular phones) can be found in a truck. To get an overview of how drivers deal with all these devices, several interviews were held.

4.1 Comparing trucks

Comparing trucks of different makes shows that all are using one or more auditory signals for displaying a problem with the vehicle. An alarm clock is also present everywhere, but with regard to other signals, the trucks are very different. Other devices that can be installed (optionally) from factory are radios, cellular phones, and navigation systems. These systems are not included in the descriptions below, except when they are integrated in some way with other auditory signals producing systems. More detailed descriptions of the audio systems installed in the trucks can be found below, but it must be noted that these findings are far from complete and can differ from type to type, and between model years.

In general, it can be said that hands free kits for mobile phones in trucks are mostly used for company phones. These phones are often blocked, in such a way that it is only possible for the truck driver to call his company and/or costumers. The result is that truck drivers often use their own, non hands free, phone to make personal calls. Unlike mobile phones, navigation equipment is not yet common in trucks; it is installed on a small percentage. Only in local distribution, companies like UPS, where delivery locations differ from day to day and the exact route matters for in-time delivery, navigation systems are quite common. An overview of third party equipment, either installed in the truck, or in the form of nomadic devices can be found in table 2.

Some truck brands are discussed in the following chapters regarding the sounds that are present in their trucks.

Table 2. Third party equipment.

Device	Remarks
Radio	
GSM	A car kit is optional
CB (Citizen Band Radio)	
Navigation	Optional, can also be integrated into the radio system
Fleet Management System	To provide communication between vehicle and fleet owner. Can have navigation and/or e-mail integrated too
Toll Collect	Toll (Maut) collecting system for Germany

4.1.1 DAF

In the current truck generation, the Digital Instrument Panel (DIP) is the main source of auditory warning signals; all those signals are supported by an indicator light. A summary of all current and near future devices using auditory signals provided by DAF can be found in table 3. The basic idea is that the perceived urgency of the sounds produced by the DIP match with a certain warning level. For the visual symbols a system of colour coding is implemented, green for information, amber or yellow for attention, and red for warnings. The Digital Instrument Panel (DIP) produces a specific auditory signal for attention, the "yellow" signal and one for the warning levels, the "red" signal, the latter indicating that immediate action is required. The basic idea behind this is the same as was implemented on the Sea King helicopter as done by Patterson (1990), see appendix A. The signals are constructed from several pulses that form a 500 ms burst, see figure 4. The "yellow" signal sounds only four times in synchrony with the corresponding icon, each of these four 500 ms bursts consist of three pulses (figure 4). The "red" warning on the other hand, remains audible and consists of a burst constructed of five pulses (figure 4). After sounding four times, the signal is presented continuously. According to literature (Edworthy & Adams, 1996), this alteration of the temporal pattern results in a difference in perceived urgency, with the "red" warning signal being the more urgent one. In case of a "red" warning, the driver has to stop the vehicle as soon as possible at a safe location; in case of a "yellow" warning it is allowed to continue driving, but the malfunction has to be solved as soon as possible. It is possible for the driver to turn the red auditory warning signal off, but the visual warning remains present. Depending on the specific cause, there are some variations in repetition rate of the signals.

There are some more sounds produced by the DIP: the direction indicator sound that could be seen as an auditory icon resembling the direction indicator relay sound. Finally, the DIP has an alarm clock function. The device will play only one sound at a time, giving priority to the warning that has the highest specified priority. If a higher priority signal is needed, the lower priority signal is turned off and the new signal will be turned on at the start of a visual pictogram blinking cycle. Thus, the maximum silent period between two auditory signals is the same as the visual symbol blinking cycle.

The latest development that has gone into production is a Digital Telematics System providing navigation, messaging service, traffic information and a fleet management system, but that part has no auditory or visual display. For audio output, the system has its own loudspeaker, it produces speech messages for route guidance and a tonal signal for incoming mail messages. For the near future, a Lane Departure Warning system is to be implemented that uses an auditory icon representing rumbling strips as a warning signal.

Table 3. Original Equipment Manufacturer (OEM) devices, standard or optional, offered by DAF Trucks using sound.

Device		Remarks
DIP	Warning Red	Continuous
	Attention Yellow	4 times
	Lights on	Yellow signal
	Direction indicator lights	Auditory icon: relay sound
	Alarm Clock	
DTS (Telematics system)		Optional, intro 2007. FMS, navigation and e-mail integrated
ACC (Active Cruise Control)		Optional, intro 2008
LDWA (Lane Departure Warning)		Optional, intro 2008 Auditory icon: rumbling

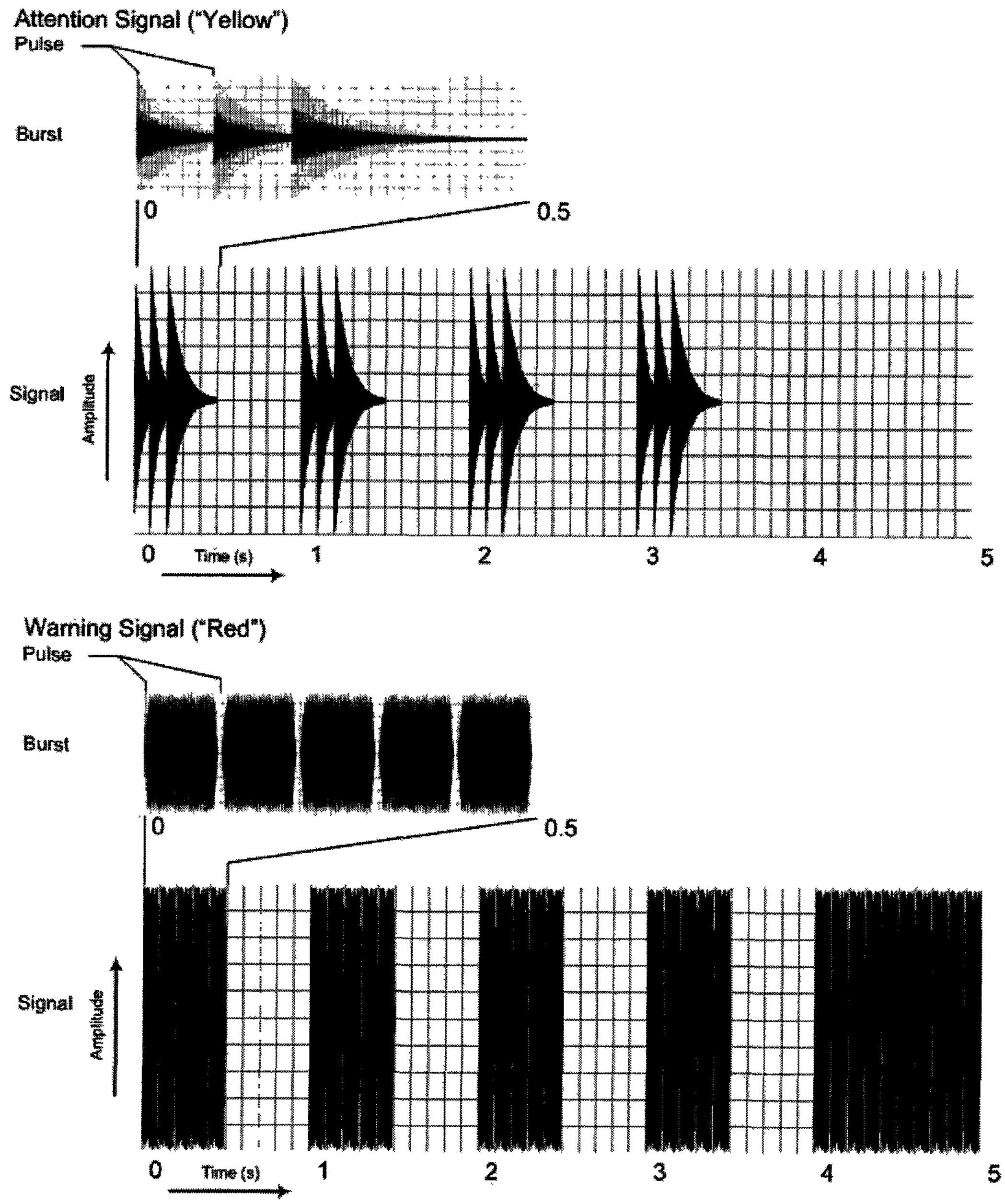

Figure 4. Oscillograms of attention and warning signals from a DAF truck.

4.1.2 Scania

Scania has, like DAF, a system where an auditory signal is connected to warning symbols on the Instrument Panel, but the system differs in the fact that only for the highest level priority an auditory signal is used. This means that the prioritization is presented as follows: green, yellow, red, red plus auditory signal. Further, Scania trucks can be equipped with a smoke alarm using an auditory signal that has a long gradual onset. To keep the driver alert, the "Scania alert" system can be installed as an option: It keeps the driver alert by displaying an irregular auditory signal from the radio speakers on the driver's side. This system is voluntary: it is operated by a switch. Both the red auditory warning signal and smoke alarm have test functions in which the sound can be heard. Finally an alarm clock function is present in the Scania.

4.1.3 Mercedes Benz

Mercedes Benz uses the same signal levels as Scania, with only an auditory signal in support for the most severe Red warnings. Mercedes-Benz equips their trucks with a fire alarm producing a pulsating auditory signal. The red warning signal is heard in the instrument testing mode when the key is turned into "drive" position, whereas the fire alarm can be heard by pressing a button. Other auditory signals are produced by the "Tempomat" (cruise control) system and for several functions of the "Telligent" automatic gearbox. Mercedes-Benz also equips their vehicles with an alarm clock; choice can be made by the driver between a buzzer or the radio coming on.

4.1.4 MAN

MAN uses auditory signals for three general levels: for red, yellow and a lower priority level that has no colour coding. Further, a 10 second signal is given when the lights are left on, and a 2 second signal when a reverse gear is selected. It has to be noted that the data acquired about MAN is older (1999), compared to DAF, Scania and Mercedes data (from 2005/6).

4.1.5 Volvo

Volvo has a radio system on offer that automatically adjusts to background noise by adapting volume to vehicle speed and engine speed. Further, ACC can be installed which has a collision warning system incorporated that uses an auditory signal.

4.1.6 Future systems

A sound management system has to be flexible with regard to future developments; some additions are quite certain to be added, others are not. On top of that, it is not known what the direction of research and development will be, and the market will be heading. The system has to be capable of dealing with these uncertainties. However, it can be said that developments that could possibly use auditory displays are expected on the following systems:

- side collision warning (SCW)
- forward collision warning (FCW)
- object detection (OD)
- parking help
- driver alertness monitoring system (European Commission, 2005)
- smoke alarm
- seatbelt reminder
- freezing road/ice warning
- road pavement monitoring system
- back up aid system (BUAS)
- low tire pressure warning
- load movement warning

Information, entertainment and communication:

- infotainment systems in general
- integrated radio

- inter vehicle communication devices (European Commission, 2005)
- extended (new) versions of fleet management systems

4.2 Interviews

An exploratory study was conducted to get a general overview of truck drivers' practices with regard to sound and auditory signals in a truck cabin. An exploratory study was used because it is better capable of developing theories and hypothesis regarding the subject of research compared to more quantitive research (Babbie, 2002). Because it is more flexible compared to a questionnaire, an interview method was chosen: it enables to go deeper into intriguing and unforeseen answers. Because the sound systems differ greatly among truck makes, and all sorts of different third-party devices are installed, it is difficult, if not impossible, to come up with a questionnaire that takes al these differences into account. These differences do make it possible to compare opinions on different systems by comparing the drivers' answers to the truck's equipment using sound. The questions to answer were:

- What is the truck drivers' attitude towards the auditory warning system, and is there much difference between drivers opinion?
- What is the truck drivers' personal priority with regard to auditory systems?
- What are important issues (for the truck drivers) with regard to the usage of auditory systems?

It has to be taken into account that people can respond differently in an interview compared to what they would do in the real situation. People can respond the way they think it is desirable and answers have to come from memory. Besides the target population of regular truck drivers, the persons who in the end are going to work with the auditory systems under investigation here, truck drivers from the DAF development department were chosen because they can be more critical: their job is to judge the truck and they can compare it to other trucks. Regular truck drivers, however, drive one truck for several years and are considered to have a quite strong positive attitude towards their "own" truck. Besides that, transport organizations do not switch often to another truck brand making the drivers' view limited because comparing their truck to another is difficult. Because of the small population used, the interview results serve only as indicators for more quantitative research to follow.

4.2.1 Method

The eleven participants for this study were selected among DAF vehicle development personnel having a truck driving licence, and regular truck drivers recruited at a delivery site at the Eindhoven DAF complex. Participants were all male, average aged 49. Two of the participants reported hearing problems. Of the participants, ten drove regularly in DAF trucks, one drove a Scania. Trucks were 4.9 years old on average, participants were driving in them for about 1.5 years.

Interviews were held using a questionnaire as a guideline, providing a general direction for the interview. During the interview, the questionnaire form, which consisted mainly of multiple-choice questions, was filled in by the interviewer. In the process extra information provided by the participant was written down. If the participant's response was unexpected or intriguing more information was asked about the specific subject. If possible interviews with regular truck drivers were held in the truck cabin and at their office desk in case of DAF development personnel.

4.2.2 Results

With regard to auditory warning signals coming from the truck it was found that most regular DAF truck drivers thought the system has only one auditory signal. Only truck drivers working for DAF development did know that there are two signals and that one is much more prominent when it sounds. Eighty percent of the participants found the system with auditory signals used for warnings supportive. Sound volume was considered to be good by ninety percent, but some said adjustability could be good for hearing impaired truck drivers. On the other hand they mentioned, it could be risky if truck drivers are able to turn the volume down. In contrast to DAF drivers, a Scania driver had never heard an auditory warning signal, although he knew of their existence as long as he had his truck: Scania uses auditory support only for the most severe category of warnings.

Table 4. Participants attitude towards supportiveness of several functions and devices using sound (n=11).

Function/device	supportive (%)	neither (%)	unsupportive (%)
Wider use of sound in future?	64	9	27
ACC	45	9	45
Parking Help	64	18	18
LDWA	33	25	42
FCW	55	0	45
SCW	55	9	36
OD	82	0	18
Automatic volume control	71	0	29
automatic mute	75	25	0

On the topic of future signals, e.g. collision warning, systems using auditory signals, most participants agreed that the systems may be useful (see table 4), but care should be taken that sounds would not be presented too often, and the number of signals should be limited. Participants considered Parking Help and Object Detection (OD), warning for objects in the so called dead corner the most useful systems (see table 4). When ordering systems according to the importance of hearing them all the time, warning systems came out as the most important, after which came the navigation system (see table 5). After those devices came the radio, cellular phones, and traffic information, all three scoring equal. The citizen band radio was considered the least important system to hear all the time. However, it became clear during the study that the citizen band radio is a device truck drivers are not willing to give up because it can provide entertainment and last minute information about traffic conditions.

Table 5. Participants' rank order of importance of hearing devices all the time (n=11).

Device	Rank order (Σ_{rank}/n)
Warning signals	2.2
Navigation	2.5
Traffic information	3.3
Radio	3.5
GSM	3.8
CB	4.6

With respect to radio volume control, for navigation messages the volume was turned down by forty percent of the drivers, or nothing was done (thirty percent). However, when participants make phone calls or use the citizen band radio, their preference went more towards switching the radio off, by forty percent, and sixty percent chose to lower radio volume. Strikingly, the manual operated radio mute function that is designed for these events was used by only one participant. Most participants were also positive about temporarily lowering radio volume (muting) in favour of warning signals: "especially for young blokes who have extra loudspeakers installed and turn the volume high" as a participant noted.

Other interesting things found during the interviews were trucks that had a VDO-Dayton telematic system installed: a system that has navigation and e-mail, giving a sound for an incoming message, integrated into one device. The driver found that the sound of an incoming message was invitational to open en read the message, also during driving. Besides the e-mail system for communicating with the office, the driver of that specific truck also had a company cellular phone at his disposal, and a personal phone in the truck. Further, the truck also had a system installed for the German Maut (Toll) system; this device produced signals when the toll amount was raised, at autobahn exits for example, or when the device malfunctions. Finally, some participants noted about navigation systems that those should specifically be adapted for trucks. A truck cannot or is not allowed to go everywhere due to height limitations or roads being prohibited for trucks or certain goods.

As stated before, caution has to be taken with generalizing these results; a small sample was used providing qualitative data. The acquired data is meant to provide insight into how truck drivers deal with auditory systems and the problems or annoyances they run into.

4.3 Discussion

Looking at the developments in the current generation of trucks, it can be said that sound is becoming a more frequently means of delivering information to the driver. Today's sound package within a DAF Truck consists of the DIP, a radio, and often a cellular phone. All truck brands studied have some form of auditory support for the general warning levels used in the instrument display. DAFs design holds a position somewhere in the middle regarding auditory support of warnings: Scania is the extreme using auditory support only for very high priority displays; on the other end of the spectrum is MAN, having auditory support for almost all warning and attention displays.

It is very likely that in the near future the number of sounds, in the form of auditory displays or as sources of entertainment and information, will be growing. This is indicated by the number of devices that are in the process of introduction, and devices that are likely to be introduced. With respect to these future developments, truck drivers seem much more cautious compared with what they have now. It is clear that they are afraid of hearing auditory signals in unnecessary situations and too often. The number of signals found in some truck cabins already is, according to theory, around the maximum that humans can learn: up to eight auditory signals were found in one truck besides navigation, radio and speech. For this reason, De Jong (2005) advised to limit the number of auditory warning signals to six. One driver indicated that directionality was a cue for finding out what was happening, not so much knowledge of the signal. Directionality seems to be an important factor overall, with general warnings used for a number of specific problems, as the signal draws attention to the dashboard where the driver can find out what exactly is malfunctioning. This behaviour works for signals that have no need for an immediate response, but for signals like a collision warning, this behaviour is typically not wanted: the driver should be able to respond immediately when hearing the sound. The meaning of the sound should be already known without added visual support. This shows the need for some way to learn the signals. Especially when more auditory signals are going to be used, and when high priority warning signals are implemented, learnability becomes an important factor. This need is also shown by the fact that drivers did not mention that there are two different auditory signals supporting visual messages on the dashboard.

The DIP has a clear build in prioritization: the most important signal will be presented. With the arrival of new sound systems, this prioritization is not so clear anymore: an LDWA signal could become audible concurrent with auditory signals from the DIP. In the end, this could cause problems already found in hospital wards and airplanes: users need more decision time or could focus on a less important signal loosing Situation Awareness with regard to their driving task. For developing a prioritization between sounds, all audio presentations have to be ordered regarding importance. A first step herein should be based on the type of task they are intended for as discussed in chapter 2; primary driving relevant, secondary driving relevant, driving irrelevant. Table 6 shows this for a number of existing and possible future signals ordered to task type. To develop the prioritization order in more detail, a more extensive task analysis is needed to decide the order within the three task types.

Table 6. A first step for deciding on prioritization: order signals with regard to task type. The numbers in the "Task type" column indicate importance; 1 indicates the most important sounds, than follows 2 and 3 indicates the least important sounds.

Device	Type	Task type	Intended Behaviour
DIP Warning Red	Earcon	1 Primary driving	stop vehicle in a safe way
Attention Yellow	Earcon	2 Secondary driving	read message on DIP
Direction indicator lights	Speech	2 Secondary driving	feedback/notice
Alarm Clock	Earcon	3 Driving irrelevant	notice
DTS Navigation	Speech	2 Secondary driving	follow route advice
e-mail	Earcon	3 Driving irrelevant	notice/read message
Traffic message	Speech	2 Secondary driving	adapt route
LDWA (Lane Departure Warning)	Earcon /Icon	1 Primary driving	steering correction
ACC (Active Cruise Control)	Earcon	1 Primary driving	note slowing front vehicle
CW (front, side, rear)	Earcon	1 Primary driving	collision avoidance
OD (dead corner)	Earcon	1 Primary driving	collision avoidance
Parking Help	Earcon	1 Primary driving	collision avoidance
GSM signal	Earcon /Icon	3 Driving irrelevant	Pick up phone/read message
GSM communication	Speech	3 Driving irrelevant	Vocal communication
Radio	Speech/var	3 Driving irrelevant	non/changing route
CB (Citizen Band Radio)	Speech	3 Driving irrelevant	Vocal communication
Toll Collect (Maut collecting system)	Earcon	3 Driving irrelevant	notice

A further factor related to priority affecting people's response, is time between messages (Wiese and Lee, 2004; Wickens, 2002). A short inter-message time can lead to deterioration of response time, while a longer time can improve response time. Besides, it is likely that collision warnings or other high priority warnings are played in high workload situations, or considerably raise workload themselves. During these situations, the driver has to have good situation awareness of the environment in which the truck is driving and the capabilities of the truck. The rise in workload and the quantity of sensory input that is not directly linked to the specific situation could cause a breakdown of situation awareness. The rise in workload, however, is not directly linked to the sounding of a warning signal; it is likely that workload will be already high before the signal starts to sound, and will remain high for some time after the signal stops due to a successful intervention. Under these circumstances it could prove advantageous to delay or prevent playing lower priority messages, or making them visible (see also the work by Van der Meijs (2006) regarding workload). A possibility to avoid short inter-messages time could be implemented in the following way: if an early stage of a severe, e.g. collision, warning is detected, less important messages should be put on hold, until the risky situation is gone (see figure 5). From a technical point of view, the same principle is used as with gradual warnings; the sensor detects a gradual change in distance. At a relative early stage, lower priority sounds could already be prevented from sounding, as shown by variant two in figure 5. Variant one shows the more common principle of putting lower priority signals on hold only as long as the higher priority signal sounds. More research is needed, however, to determine useful intervals. If this interval is too short, the beneficial effect will be minimal. Besides this, technical properties of the devices must be capable of implementing such an extra level.

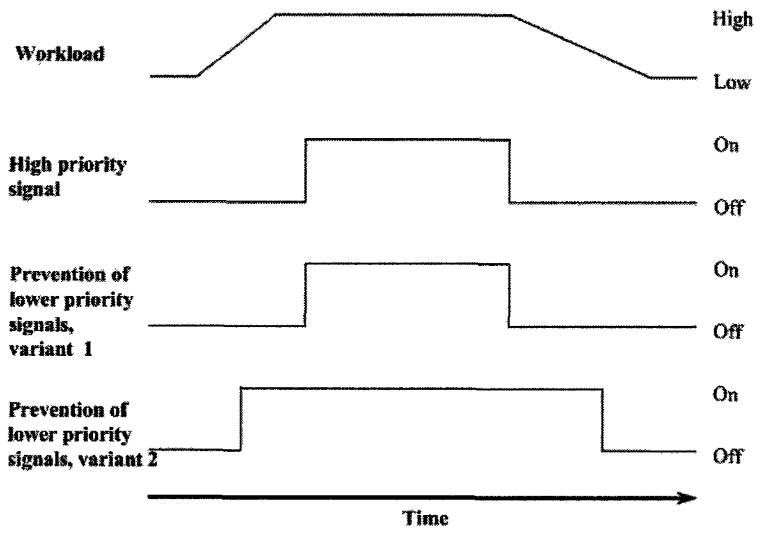

Figure 5. Prioritization mediating workload.

Returning to the interviews, it can be said that the mute button, present on most radios, is hardly used. Depending on the situation the radio volume is turned down automatically, by hand, or the radio is turned off. Truck drivers seem willing to give up continuous radio broadcast in favour of auditory messages they find more important. In a way this happens already by lowering the radio volume manually or automatically, depending on the manufacturer, when the phone, navigation or citizen band radio is used. The statement of a driver that the auditory signal presented with an incoming email is attracting attention to opening and reading the message at once clearly shows that auditory signals can draw a great deal of attention. It is questionable, however, whether something like an email message should attract so much attention during driving.

With respect to the technical challenges in developing a sound management system, a clearly difficult factor is shown by the ever growing number of non OEM devices found in a truck. It is unlikely that every fleet operator in the future will only install OEM equipment; when a fleet uses several truck makes, it is likely they want one system for every truck make, instead of truck-make-specific systems. Ideally all systems that are marketed for operation in a truck should make use of standardized sounds, which however, is not very likely to happen in the near future. Beside that, truck drivers can bring in their own devices, like cellular phones adding another uncertain and distracting factor. Finally, it is worth noting that it is typical to find two cellular phones within a truck cabin but only one car kit, mostly for the company phone. Although not allowed by law, it is highly likely that the private phone is also used when driving, thus the limited positive effect a car kit has, becomes even smaller. The most effective measure would be to ban the use of cell phones by vehicle drivers completely. To achieve this, a regulatory framework is needed. Until that moment, installing a car kit is the only measure possible.

To summarize, the number of devices that use sound to present information to the truck driver is ever growing. Not only for presenting information regarding route or the state of the vehicle, but also providing information to raise SA on the primary driving task. These developments taking place should direct the HMI engineer's focus on human factors like learnability, perceived urgency, annoyance and priority. This should avoid conditions as occurred in hospital wards and airplanes discussed earlier in this report. Beside the design of auditory displays, muting radio and prioritization between signals are measures that are relatively easy to implement. An experiment will be designed to study the effectiveness of interventions as mute and prioritization, and to show implications stemming from concurrent sound presentation.

5 Experiment

5.1 Introduction

This experiment was carried out to provide insight into how drivers will deal with the effects of this growth in auditory stimuli. As discussed in chapter 4, all information provided to the driver, from the environment as well as from the truck itself, can be categorized regarding their relation to primary driving relevant tasks, secondary driving relevant tasks, and irrelevant tasks. It is vital that the signals relating to the primary relevant tasks are correctly identified: these signals provide information for successful and thus safe performance on the driving task.

Criteria used to judge sound are looking at attitudinal aspects (Edworthy & Adams, 1996, Otto et al., 2001), into signal detection (Antin, Lauretta & Wolf, 1991), or into behavioral aspects. When investigating on behavioral aspects, one can use measures like operational errors (Green, 2000), response time (Ho & Spence, 2005; Ho, 2006), or situation awareness (Endsley, 2003; Denford, 2004). Situation Awareness (SA) was chosen as a criterion to judge the effect of different principles regarding sound devices. Most behavioral measures look at a single aspect, making it difficult to obtain insight into the total impact of changes in interface design on the behavior of the operator. SA is an exception to this, as it measures more broadly to what extent an interface influences awareness. SA is general recognized as "a critical and often elusive foundation for good decision making" (Endsley, 1998), and has been used to evaluate a wide range of systems including the fields of aviation, air traffic control, nuclear power control, medicine and driving. Coming back to the specific task of truck driving, the driver needs to have sufficient driving relevant SA, as explained in chapter 2, for successful performance of the driving task. All aspects increasing workload or providing ambiguous information can prove a limiting factor on SA or directly on the primary driving task performance. The present experiment was designed to find out to what extent multiple auditory stimuli can interfere with the task of truck driving by limiting relevant SA, and to investigate possible solutions to such a problem. The following hypotheses were formulated:

- Overall SA will be lower when more signals are presented at the same time.
- Primary task unrelated signals will disturb detection and understanding of primary task related signals;
- Auditory signals can distract from visual stimuli.
- If auditory presentations are prioritized, and the radio is muted, SA improves compared to a situation with multiple auditory stimuli presented at the same time.

Beside problems related to the quantity of auditory presentations, it was desirable to gain insight into a somewhat different concept; the need for an automatic volume control system. It was found that automatic adjustment of signal intensity to background noise was a standard criterion in recommendation documents. Studies investigating the effect of this issue on system users, however, were not found. Based on the recommendations it is expected that signals that are adjusted to background noise are perceived more similar than unadjusted signals.

5.1.1 Objective SA measures

Returning to the topic of SA, it is possible to measure it in a simulator or in real environments (Endsley et al., 1996), and SA can be measured both in objective and subjective ways. The most widely used objective measure for this is the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1998). A simulation freezes at random; at the time of this freeze, a series of queries is provided to the system operator. His knowledge is than assessed by comparing the operators' answers on queries to the actual situation. This is done for all three levels; perception, comprehension and projection of SA. To construct the queries, an extensive task analysis is required. Another method of assessing objective SA, but now also feasible in a real environment, is the Situation Present Assessment Method (SPAM) (Banbury and Tremblay, 2004). This method employs queries during the task, thus limiting the influence of memory compared to the SAGAT method. Most research regarding SPAM uses either present or future related questions, thus at the SA2 and SA3 levels to prevent memory becoming an important factor. Disadvantageous is that it is more difficult to measure SA using the SPAM method during dangerous or high workload situations because the questions will distract from the actual task.

5.1.2 Subjective SA measures

Regarding subjective SA measurement, Situation Awareness Rating Technique (SART) is a commonly used measurement method developed by Taylor (1989). SART asks an operator about his perception concerning: 1) demand on their resources, indicating workload, 2) supply on their recourses, and 3) understanding of the situation. These three scales, froming the so called 3-D SART measure, can be converted into a 1-D overall SART measure (Endsley, 2003). A completely different method, not using queries, is the hazard perception method (Banbury and Tremblay, 2004). Participants have to watch a video and should respond when they see a hazard developing. In this way both categorical (hit or miss) data as well as response time data are obtained. Several variants of this method were developed providing more specific measures like earliest time a hazard becomes predictable or the moment of maximum hazard. Many more methods for measuring SA exist, including combinations of different methods (see for instance Endsley, Bolte and Jones, 2003, or McGuinness, 2004)

5.1.3 Experiments

The present study specifically aims at the effects on behavior of sound alone, and not to the complete user interface of the truck, nor does it aim at driving performance in specific traffic situations. Because of this, and the added complexity of a real life or simulator environment, scenarios were used made up of small slide-shows depicting traffic situations, of course supported by sound. This is an interesting aspect, because if such a method is successful, it can provide a fast and low-cost solution for investigating interface adaptations. These simplifications of the real world are often used in research. For example, Ho, Tan and Spence (2005) have implemented video scenarios in a whole range of experiments, while Antin, Lauretta and Wolf (1990) used a video game to simulate workload stemming from a driving task. It should be noted that it is likely that this aspect limits generalizability in some aspects; the task becomes mainly a visual and auditory detection and understanding task: the response task (see chapter 2) of dealing with the environment is eliminated. The experimental design creates some constraints on the SA measurement method to be used. Objective SA measured with the SAGAT method is easy to implement, the experiment consists of short slide-shows, which leaves no room for questions to be asked during the slide show. Further, the SAGAT method makes it possible to implement a more elaborate questions list. The SAGAT and SART measures show no direct correlation according to Endsley (1998). She discusses that SAGAT provides more insight on actual SA, whereas SART can be viewed as a measure for perceived SA: SART showed high correlations with confidence level and subjective performance. It is interesting to measure both these aspects to provide insight into people's confidence in their SA. It was decided to implement both the SAGAT and SART method into the experiment.

Because of the different concepts that need to be measured, two experiments were designed. The first experiment studies the influence of different sound interface principles on SA. The second experiment investigates whether automatic volume control has benefits for the system user.

5.2 Experiment 1

5.2.1 Method

Three different sound conditions were designed; a one signal condition used as a baseline; a multiple signal condition consisting of the one signal condition with several other signals added; and a prioritization/mute condition similar to the second condition, but now signals follow up each other and the radio is muted. The experiment consisted of a 2-way factorial design of six different traffic scenarios and the three sound conditions mentioned, thus creating a total of 18 conditions.

For means of measurement, both an objective SAGAT based method and the subjective SART method were implemented. It should be noted that, because of the limitations posed by the slide show set-up, the SAGAT based queries were not based on task analysis, but only on the objects that were visible and the sounds that were audible, as the experiment did not consist of a driving task. The queries did not simply ask for the auditory signal names however, but to prevent the experiment becoming a pure detection task, asked for the signal meaning instead (Queries can be found in appendix B). The participants' score on the SAGAT query thus represents level 2SA (see chapter 2). For instance the queries for the Lane Departing Warning Assistant (LDWA) signals were formulated as "I cross the road markings too far to the left", and "I cross the road markings too far to the right". Regarding the SART questions, a seven point answering scale was used, ranging from "very little" to "very much". Exact formulation and questions can be found in appendix B (in Dutch).

Participants

Participants were recruited from within DAF Trucks, from either a truck demonstration group or from the vehicle testing department. All participants were highly experienced, both with truck driving in general, and with most sounds that were used, thus preventing the experiment to focus on signal learning. Thus, the group of participants was relatively homogenous. In total, twelve truck drivers, on average aged 44 (SD = 8.2) participated in the experiment.

Apparatus

The experiment was run on a personal computer and programmed in Macromedia Authorware. To create a more realistic setting, a DAF CF truck and beamer setup were used in a closed room, projecting the Authorware program on a screen located 6 m in front of the truck. Participants sat in the driver's seat thus enabling them to view the traffic situations through the wind screen (see figure 6). Participants could operate the program using a mouse on a shelf mounted on the drive tunnel between the in–cabin seats. Because of the many different sound sources, in the form of background noise and from different speaker locations in the truck, it was decided to record all sounds and present them mixed together to the participant by headphones. This made it possible to present all needed stimuli using one computer system without timing problems. All sounds were recorded in stereo using in ear microphones (type: HEAD BHM III) on the driver's position in the truck. For playback, the personal computer playing the file recordings was equipped with a RME DIGI96/8 PAD 24 bit analog I/O soundcard, connected to a Head Acoustics HPS IV amplifier equipped with Head Acoustics HA II electrostatic headphones.

Figure 6. At the left panel: experimental setup with truck and beamer; at the right panel: view from the driver's position showing the screen on which the traffic situations and questionnaires are presented.

Stimuli

The stimuli used for the experiment consisted of photographs of traffic situations and sounds that matched to the situation that was shown. With these stimuli, traffic scenarios that could possibly occur while driving a truck were created. The sound conditions consisted of in-truck recorded audio: a combination of background noise, six auditory signals, navigation messages and radio. Three sound conditions were provided in a within subjects design with six different visual driving scenarios, three located within a city and three on a highway (see appendix B for details about stimuli used in the experimental conditions). The 18 scenarios were presented in a randomized order to the participants. The scenarios started with a picture showing a traffic situation and a textual explanation about where the truck was heading. When the participant pressed a button, a ten second audio file was played. The basis of each audio file consisted of background noise, either recorded at 30 km/h or at 85 km/h, and one out of three primary driving task related signals, a "red" warning, CW or LDWA signal (see appendix B for details). After about six seconds, the primary driving task related signal became audible and, at the same time, the first picture switched to a second picture. This second picture showed the traffic situation further in time (see figure 7). The primary driving related signal was presented at the same moment in every scenario to provide good comparisons for later analysis. After 10 seconds, when the audio file was terminated, the picture was also deleted from the screen.

As mentioned, three different sound conditions were designed, first of al, a one signal condition that contained only the basis that was used in al conditions; background noise and a primary driving related signal. For the multiple signal condition, radio was added, and a combination of four auditory displays. These auditory displays matched the traffic situation that was shown and consisted of tonal signals and navigation messages, all having a lower priority than the primary driving task related signal. The prioritization/mute condition used the same sounds as the multiple signal condition but now signals were presented one at a time, each new signal eliminating the previous signal. For realism, sometimes the direction indicator sound was added, this was however not mentioned, nor asked in the questionnaires. To recapitulate, the sound conditions were designed as follows:

- one signal condition: consisting of background noise and a primary driving task relevant auditory signal;
- multiple signal condition: consisting of background noise, a primary driving task relevant auditory signal, radio noise and four other auditory signals;
- prioritization/mute condition: consisting of background noise, a primary driving task relevant auditory signal, radio noise and four other auditory signals. Signals are played in order of importance; the less important signal was stopped for a more important signal. Radio was muted whenever a signal was played.

More specific information regarding the sounds used and visual scenarios can be found in appendix B.

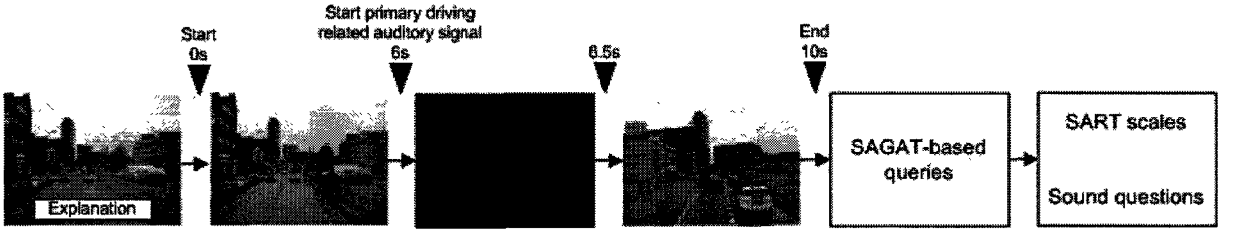

Figure 7. Time line showing the traffic situation to questions cycle.

Procedure

Participants were welcomed, and the experimental procedure was described to them. The way the program worked was explained, and it was emphasized that they should try to experience and perceive the traffic situations as they would do when they were really driving a truck. Next, the participants were seated in the truck, and were shown the mouse and head phones. The experimenter stayed present during the introductory part of the experimental program for answering questions. The first stage consisted of a familiarization with the six tonal sounds that were used in the experiment by letting participants activate the sounds and providing a description of the meaning of the signals. After this auditory training stage, participants received a textual explanation of the traffic situations, followed by a first traffic situation and questions for training. The cycle of a traffic situation followed by questions was repeated for all traffic situations used in the experiment. Figure 7 shows the cycle of the traffic situation and questions. It was presented by a first picture, accompanied by a textual explanation of where the participant was driving to. The participant himself could choose how long to watch this picture and read the text. At pressing the 'next' button, the textual explanation would disappear and the slideshow combined with sound was started. After 6 seconds, the picture was replaced by another one with a black screen presented between them to obtain a better separation between the two pictures. The second picture presented the traffic situation in a later stage, and was always accompanied by a warning signal. The second picture remained visible for 3.5 seconds and was followed by a first page of questions.

The first page consisted of the SAGAT-based questions and, after being filled in by the participant, was followed by a second page that incorporated 3-D SART questions and three sound related questions. The training session was completed by filling in the second page. Now the participants were offered one last time to practice the auditory signals before entering the real session. At this time, the experimenter stepped out of the truck, leaving the participant alone for better concentration and to prevent distraction. The cycle of presenting the traffic situation followed by the two pages of questions was repeated for all 18 experimental conditions.

The final stages of the experiment consisted of questions regarding the traffic situations over all, the sounds and management principles used during the experiment, and some general questions regarding the participant.

5.2.2 Results

There were no missing data points, as the program did not allow skipping questions. The data was checked for participants not performing seriously or answering in an extreme manner. As no outliers were found, the complete dataset was used for analysis. To provide insight in the participants evaluation of the experiment, three closed end questions were asked on finishing the experimental program. Participants could judge the statements on a seven-point scale ranging from one for very bad, to seven for very good. Capability to visualize the traffic situations was judged as "reasonably good". The participants found the sounds that were used were realistic, judging realism as "good". Recognition was also judged as being "good", directionality was perceived as somewhat more problematic: capability to detect direction was judged as "nether good, nor bad". Exact results can be found in table 7.

Table 7. Items for evaluation of the experiment. Answering possibilities range from 1 for "very bad" to 7 for very good, *n* = 12.

Item	*M*	*SD*
Capability to visualize the traffic situations	4.67	1.56
Realism of sounds used	6.00	0.60
Recognition of sounds used	5.75	0.62
Capability to detect signals' direction	3.50	2.02

The SAGAT score was calculated by comparing answers to the actual pictures and sound files; correct answers were recoded as 1, incorrect answers as 0, which made it possible to calculate a percentage of correct answers per participant and thus their SAGAT score. Because the overall SAGAT score consisted of several different more detailed components of interest, it was decided to calculate some more variants using the same method:

- driving related SAGAT, preserving only the items that were driving related;
- visual SAGAT, preserving only the items that were related to visual perception;
- primary auditory signal SAGAT, preserving only the items related to the primary driving related warning signals used in every condition. This signal started at the same time as the second picture came up. Three different signals were used alternately as the primary signal in each situation.

The SAGAT queries that made up each item can be found in appendix B. The mean SAGAT score on all variants of the SAGAT measure can be found in figure 8.

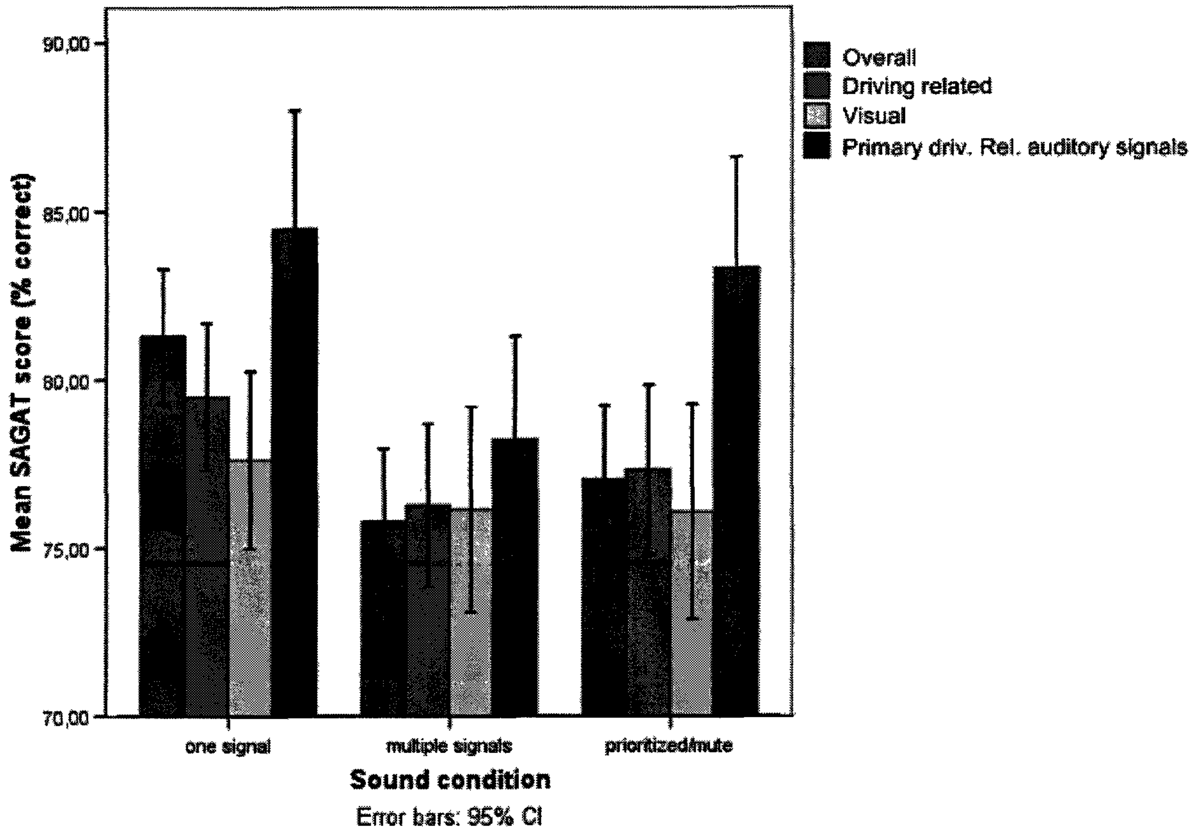

Figure 8. Mean overall SAGAT scores for all three sound conditions.

A two way (2 X 6) repeated measures ANOVA was used for hypothesis testing, with the sound condition as the repeated measure; the dependent variable was the SAGAT score. Because of the influence of traffic-situation complexity, the visual scenarios were added as an extra factor. The Repeated Measures ANOVA method was used for analysis of all four variants of the SAGAT score. Effects of the factor of interest, sound condition, and the visual scenario factor can be found in table 8 for all variants of the SAGAT measure. Interaction effects were not found. All but the visual-only SAGAT score show significant effects for the sound condition. Looking closer at the Overall SAGAT score, contrasts revealed significant effects between the one signal condition and the multiple signal condition (F (1, 12) = 23.72, p < .001), and between the one signal condition and the prioritized/mute condition (F (1, 12) = 17.49, p = .002). In both cases, a higher SAGAT score was reached in the one signal condition. Overall SAGAT consists of all SAGAT query items, including several driving unrelated items such as radio, GSM and Email. The important aspects of SA are, however, the driving related items, as those can influence performance on the driving task directly. The same tendency as with the overall SA score, although less strong, was found for the driving related SA score (see figure 8). Contrasts again showed that in the one signal condition participants reached a significantly higher SAGAT score compared with the multiple signal condition (F (1, 12) = 6.38, p = .028). Differences became smaller, however, and thus only a nearly significant difference was found between the one signal and the prioritization/mute condition (F (1, 12) = 4.55, p = .056). The same tendency was shown again when only the visual part of the SAGAT score was analyzed, but now no significant differences were found. The final repeated measures analysis done on the

SAGAT score considered only the items related to the primary driving task related signals. Whereas the other analyses showed all the same trend, contrasts revealed a different pattern. The SAGAT score at the one signal condition was found to be significantly higher compared with the multiple signal condition (F (1, 12) = 7.57, p = .019). In contrast to the other findings, the multiple-signal condition and the prioritization/mute condition were significantly different (F (1, 12) = 5.43, p = .040), participants scoring higher on the latter one.

Table 8. Effects of sound condition on the different SAGAT scores, n=12.

SAGAT score	*Within subjects factor*	*df*	*F*	*Sig.*
Overall	Sound condition	2	16.37	< .001
	Visual scenario	5	10.94	< .001
Driving related	Sound condition	2	4.54	.022
	Visual scenario	5	13.38	< .001
Visual	Sound condition	2	1.28	.297
	Visual scenario	5	19.11	< .000
Primary driving related signals	Sound condition	2	4.71	.020
	Visual scenario	5	0.63	.679

The SART measure consists of three dimensions, each rated from one, meaning "very little", to seven, "very much". The three dimensions can be looked at separately, but also an overall 1-D SART measure can be calculated: $SA_{calculated} = SA_{Understanding} - (SA_{Demand} - SA_{Supply})$ (Endsly, 2003). All means can be found in table 9, answering options ranged from one, indicating "very little" to seven, indicating "very much". Again, a repeated measure ANOVA was used to analyze the findings. Of all three SART measures, only "SA demand" revealed a significant effect for sound condition (F (2, 12) = 11.02, p = .000). Participants judged the one signal condition as less attention demanding compared to the multiple signal condition, and as the prioritization/mute condition. The other two SART items remained at a same level regardless of condition. The effect found in the 1-D SART score (F (2, 12) = 4.53, p = .023) was completely caused by the "SA demand" dimension.

Table 9. Mean responses on SART questions, n=12.

	One signal		Multiple signals		Prioritization/mute	
SART item	*M*	*SD*	*M*	*SD*	*M*	*SD*
attention demand	4.54^{A}	1.23	5.04^{B}	1.23	4.89^{B}	1.22
attention understanding	5.03	0.99	5.07	0.97	4.92	0.92
SA supply	5.07	1.09	5.07	1.03	5.06	0.96
1-D SA	5.56^{A}	1.96	5.10	1.83	5.08^{B}	1.73

Means are significantly different at a p < .050 level between sound conditions that have different letters. For example, "attention demand" in the "one signal" condition having letter "A", is significantly different from "attention demand" in the "multiple signals" condition having letter "B".

The last series of questions concerning the traffic situation dealt with the subject of sound. Participants could judge the three items on a scale ranging from one, "very bad", to seven, "very good". Mean answers across the different sound conditions can be found in table 10. Overall, it was found that both the audibility (F (2, 12) = 5.08, p = .015) and recognition (F (2, 12) = 5.94, p = .009) items significantly depended on sound condition. Looking closer at the differences in table 10, audibility was rated significantly worse in the prioritization/mute condition, compared to the one signal condition. The difference between the multiple signals condition and the prioritization/mute condition was just not significant. Looking at the next item, recognition, differences were slightly larger, but still having the same direction. The last item of comfort showed smaller non significant differences.

When comparing objective SA measures with subjective SA measures, weak relations, although significant, were found. Significant Pearson correlations were found between the overall SAGAT and SART

"SA demand" measures (r (216) = -.23, p = .001), the driving related SAGAT and SART "SA demand" measures (r (216) = -.20, p = .003) and between the visual SAGAT and the SART "SA demand" measures (r (216) = -.19, p = .006).

Table 10. Differences in response to questions related to sound, n=12.

	One signal		Multiple signals		Prioritization/mute	
Sound item	*M*	*SD*	*M*	*SD*	*M*	*SD*
Audability	5.56^{A}	0.65	5.33	0.84	5.32^{B}	0.77
Recognition	5.31^{A}	0.93	4.6^{B}	1.50	4.61^{B}	1.43
Comfort	5.11	0.97	4.64	1.34	4.69	1.32

Means are significantly different at a p < .050 level between sound conditions that have different letters. For example, "Audibility" in the "one signal" condition having letter "A", is significantly different from "Audibility" in the "Prioritization/mute" condition having letter "B".

After finishing the experiment, participants were asked to rate the sound management principles they had gone through during the experiment on a 7-point scale with 4 being neither negative nor positive. Stopping less important signals, prioritization, was perceived as slightly positive at M = 5.33, SD = .78. The same holds for using radio mute when warning signals are presented (M = 5.33, SD = .99), and radio mute when navigation messages are presented (M = 5.58, SD = 1.17).

5.2.3 Discussion

The main goal of this experiment was to investigate the influence multiple auditory signals have on perception and cognition, and thus drivers' SA of the environment, which those signals are a part of. Analysis revealed a significant deterioration in objective SA in conditions having multiple signals. This effect was found in SA measurements that took sound into account. No effect was found, however, for visual SA. The effect of the multiple signal condition was partly found in the subjective SA measure: participants rated the situation as more attention demanding when multiple signals were presented. Beside the one signal condition used as a base line and the multiple signal condition, a third (prioritization/mute) condition was implemented in the experiment presenting a possible solution. Participants rated this prioritization/mute condition nearly equal attention demanding as the multiple signal condition. Although the same was found regarding overall objective SA, looking more closely at the important audio signals, the primary driving related signals, a significant improvement was shown for the prioritization/mute condition in comparison with the multiple signal condition. This effect contrasted with the other effects found in objective as well as subjective SA, and was supported by comments afterwards. Participants stated they did not perceive the multiple signals and prioritization/mute condition as different. Their opinion was that both conditions using multiple sounds were much more difficult to interpret than the one signal condition. The findings also indicate that less important auditory signals can deteriorate perception and cognition of more important signals: in the one signal condition, SA regarding the primary driving related signals was significantly better than in the multiple signals condition.

The results clearly show that human resources, in the case of perceiving and understanding auditory stimuli in a driving situation, are limited. With a growing number of auditory signals in an otherwise same situation, perception and cognition of sensory sources worsens. These results are also supporting multiple resource theory (Wickens, 1998), regardless of the amount of auditory stimuli offered, visual perception and cognition stays at a constant level. This does not necessarily mean that there is no effect like auditory preemption that to some extent contradicts multiple resources theory (Seppelt & Wickens, 2002). For example, it could be that the visual SAGAT queries were relatively easy. Furthermore, each traffic situation was shown three times which could cause a learning effect. Another cause could be that the audio signals attracted limited attention, not being presented through a device, but through headphones. For example, the red and yellow warning should in a real event draw attention away from forward vision towards the display where the driver can find out what is wrong with the vehicle. Comments afterwards indicated that participants themselves found it harder to process all information, for instance, stating being "overfed" by audio signals. Responses in this direction confirmed earlier findings in other fields of profession, by Patterson (1990) among aircraft crews, and as reported by Edworthy and Adams (1996) among hospital personnel; both discussed numerous interviews.

It was tried to give participants the feeling of driving a real truck during the present experiment. It should be noted, however, that there is a serious difference in reality compared with a real or with a simulator setting, in which SA measurements are normally carried out. In slightly different settings, not using SA measures, such abstractions of the real world have proven successful for comparing changes in interface principles. For instance, Ho and Spence (2005) conducted a series of studies using movie fragments for testing detection speed and accuracy of different warning modalities. Antin, Lauretta and Wolf (1991) used a simple driving game in a signal detection study to obtain more ecological validity. A stationary setup like the one used, however, will probably underestimate effect sizes, indicating that the effects that were found are very robust. Even so, it would remain interesting to compare results found in the present study with a similar simulator-based study to provide more insight into the method's ecological validity. If similar findings would be obtained, the slide-show scenarios could provide a relatively cheap and quick way of interface evaluation. Possibly extended versions of the scenarios that incorporate more pictures or movie fragments could also be used, thus enlarging realism.

Comparisons between the objective and subjective SA measures showed only some weak relations. This supports Endsleys (1998) findings that SAGAT and SART are uncorrelated and measure different concepts. The SART measure indicated that participants were only able to note large differences in sound conditions. For example, the one signal condition versus the multiple signals condition. This was confirmed in conversations with the participants, they indicated that they did not note the difference between the multiple signal condition and the prioritization/mute condition. The SAGAT measure, conversely, was able to measure the difference between the multiple signal condition and the prioritization/mute condition.

Although the signals used were chosen for the experiment because they should have been relative familiar, several participants still noted that it was hard to remember the meaning of some audio signals. Another problem mentioned was difficulty with filling in the collision warning in the SAGAT query. Several participants did not always understand that it provided information regarding an unseen traffic participant to the left or right of the truck. Although this principle was explained at the beginning of the experiment, participants probably associated the signal with DAF its ACC system that only signals a collision risk with a vehicle in front of the truck. Thus, the method used needs fine tuning on the SAGAT query in combination with the signals used, to obtain a fully correct and unambiguous meaning of all items, obtaining clearer results. This method seems to be an appropriate way, however, to study the effects on interface adaptations. As it is a means for evaluating interfaces, comparison with a simulator based experiment would be interesting to obtain more insight into the ecological validity of the method that was used.

Results indicate that the 3-D SART measure did not work properly as answers to the "attention understanding" and "SA supply" items were constant in every experimental condition. Causes could be found in insufficient understanding of the "SA supply" and "understanding" items. Also the experimental setup, in which participants only had to perceive without the need for a response could have caused this. Results found by Selcon and Taylor (2000) using the SART method were similar. The biggest changes were again shown in the "demand" item caused by experimental conditions, the other two items not being significantly different in most cases. Besides insufficient understanding, it is also possible that humans find it difficult to judge their supply of attention and their understanding of a situation. An option would be to implement the 10-D variant of the SART measure, which consists of ten more specific items (Endsley, Bolté & Jones, 2003). In case of the present study this was not done because it would add considerably to the length of time needed for participants to spend on the experiment. Although the subjective SA measure did provide interesting results, the measure may be improved, for instance by testing the questions for correct understanding and unambiguousness or by implementing the 10-D SART measure.

Some comments need also to be made about the auditory signals used, based on discussions with participants. It was mentioned that there were problems distinguishing between the Red and Yellow signals, which could be caused by both of them having the same rhythm in the experiment. In a normal situation, the red warning starts as it was used in the experiment, but after four pulses, it sounds continuously. This can be considered as the most distinguishable property between the Red and Yellow signals. It could therefore be considered to use only one type of burst for red and yellow, and distinguish between them by the continuity aspect. The other problem mentioned in conversations was the lack of directionality within the Collision Warning signal. The problem could lie in the method that was used in this experiment, using recordings and headphones for presenting the sounds. It should be noted however, that especially for such an important signal, the directionality aspect should be tested extensively on the road, also with other sounds present, before implementing it in a production vehicle. Especially for collision warning systems, a fast and correct detection of direction is crucial for a successful implementation. Furthermore, interactions between the signal and other sounds could also play a role in the deterioration of directionality.

Results found were unambiguous; adding more auditory signals limits accuracy of SA, and counter measures in the form of prioritization and radio mute have a positive effect on SA and thus on correct signal recognition. This worked despite the fact that participants were not consciously aware of the countermeasures taken in the form of prioritization and radio mute. Numerous improvements in the SA measurements used can be made, fine-tuning them specifically for the research method used. If this is done, and especially after verification of the results in a simulator environment, the method is promising for investigating changes in interface principles. Besides the effects of the different sound principles, the experiment provided also some practical insight into the signals used.

5.3 Experiment 2

5.3.1 Method

A second experiment was designed to study possible advantages of automatic intensity adjustment. To achieve this, participants were asked to compare signals with different intensity levels under various background noise conditions on several attitudinal properties. As the two experiments were executed in a single procedure, the participants for this experiment were the same twelve persons as with experiment one. Participants' characteristics can be found in chapter 5.2.1.Information regarding the equipment that was used can be found also in chapter 5.2.1.

The sound fragments created for the experiment had a total duration of ten seconds, the schematic design of the fragments used can be found in figure 9. Three truck background noise levels were used; 30 km/h, 85 km/h and a "fan" condition. The fan condition was the noise of a truck driving with the radiator fan turned on, one of the loudest background noise conditions to be met when driving a truck. The CW auditory signal, already used in the first experiment (see appendix B for properties) was implemented in an "unadjusted" variant and a variant with "adjusted" intensity depending on the background noise condition (see table 11). These two variants were compared by the participants. In the 85 km/h condition, however, the two signals were exactly the same, thus creating a manipulation check. Order, of both the signals and the background noise conditions was randomized, thus resulting in a total of five comparisons that participants were asked to make (see table 11 for details).

Figure 9. Time line of experiment 2, showing the presentation of background noise with two auditory signals to be compared on five properties by participants.

Table 11. Stimuli used: different intensity levels of background noise and the combination of auditory signals used in each condition.

Background noise condition	Background noise intensity (dB)	Signal A	Signal B
85 km/h	72	unadjusted	unadjusted
30 km/h	67	-5 dB	unadjusted
30 km/h	67	unadjusted	-5 dB
fan	83	+11 dB	unadjusted
fan	83	unadjusted	+11 dB

The signals were judged by participants on five properties, namely distinctiveness, loudness, perceived urgency, annoyance, and appropriateness (see appendix B for the questionnaire in Dutch). Each time, a participant was asked to compare the two auditory signal variants (see table 11) by judging to what extent they differed on the five properties. This comparison judgment was done using seven-point scales where the boxes left and right from the middle indicated whether the first or the second auditory signal was associated more to the judgment property. The middle option was neutral; it indicated no difference between the two signals on a judgment property. The experiment was integrated into a single procedure with the first experiment, by carrying it out directly after the first experiment.

5.3.2 Results

After reviewing the data, it was decided to leave two participants out of the analysis based on the manipulation check, a comparison between two exactly similar auditory signals. The two participants gave only extreme answers in preference of one signal, although both auditory signals were exactly similar. All other participants judged the 85 km/h background noise condition correct, noting no difference between the two signals; this condition was not analyzed further.

The judgment properties were analyzed on their association to either the "unadjusted" or "adjusted" variant of the auditory signal. Answers were recoded in such a way that a value of zero indicated no perceived difference on a judgment property between the compared signals. Negative numbers indicated that the judgment property was being perceived as more associated to the "unadjusted" auditory signal, positive numbers indicated that the property was more associated to the "adjusted" auditory signal, see table 12. In contrast to experiment 1, participants' made direct comparisons between two signal conditions instead of making separate judgments for each signal condition. Because of this, t-tests were used instead of a repeated measures analysis. Paired samples t-tests with Bonferroni's adjustment were used to find significant perceived associations of the judgment properties towards one of the two signals.

Significant associations between the loudest signal variant and almost all judgment properties were found: this was the "unadjusted" signal in the 30 km/h condition and the "adjusted" signal in the fan condition (see table 12). Especially in the extreme loud "fan" background noise condition the association was strong for the distinctiveness and loudness properties, as all participants indicated the most extreme answer, see table 12. The effects found were expected for the distinctiveness, loudness and perceived urgency properties. But effects for the annoyance and appropriateness properties were expected to be positive in both background noise conditions.

Table 12. T-tests for association between signals and properties. *n* = 10.

	30km/h background noise				"fan" background noise			
Signal Judgment property	*M*	*SD*	*t*	*Sig.*	*M*	*SD*	*t*	*Sig.*
distinctiveness	-2.25	0.76	-9.43	< .001	3.00	0.00	-	-
loudness	-2.55	0.76	-10.58	< .001	3.00	0.00	-	-
perceived urgency	-1.55	1.30	-3.77	.004	2.15	1.72	3.96	.003
annoyance	-1.05	1.04	-3.20	.011	1.70	1.25	4.30	.002
appropriateness	-1.85	1.13	-5.12	.001	2.50	1.00	7.91	< .001

Negative means show a association towards the unadjusted signal, positive means towards the adjusted signal.
Test value: zero, the value for no difference between the compared signals.
Significance with Bonferroni adjustment: $p < .010$.

As a final question, it was asked whether participants would prefer an automatic volume control. This was done using a scale ranging from not preferable at all (1) to very preferable (7). Participants judged automatic volume control as being reasonably preferable to preferable ($M = 5.50$, $SD = .80$).

5.3.3 Discussion

Participants perceived the strongest association between the judgment properties and the loudest variant of the auditory warning signal in every background noise condition. For the "loudness" property, this effect is clear cut: participants clearly distinguished the loudest signal of the two. The response to the distinctiveness and urgency properties was also as could be expected, the more intense signal is also more distinct over background noise, and raised intensity contributes to a higher perceived urgency (Edworthy & Adams, 1996). The hypothesis that signal intensity adjusted to background noise would be perceived more similar was not supported by the results from the last two properties, annoyance and appropriateness. Here, results are similar to the other properties; both annoyance and appropriateness were more associated with the loudest signal instead of to the adjusted signal.

The findings do not provide clear support for automatic volume control; however, care has to be taken in interpreting the results. First of all, the strength of automatic intensity adjustment lies in easy signal detection, independent of the background noise intensity level. This aspect was not tested within this experiment. Furthermore, attitude towards the auditory signals was studied by making direct comparisons; something that is not possible in real life situations. The experiment was also limited because only two different variants of the auditory signal were presented at each background noise level. It would have been interesting to see what participants' reaction would be when the loudest version of the signal was presented in the less loud 30km/h background noise condition. This would be interesting because it happens in practice often that auditory warning signals are presented overly loud to make sure they are detectable no matter what the background noise condition is. There is a problem, however, in the "fan" background noise condition; with making the signal even louder it could become painful or even dangerous to human hearing as the loudest variant used was already nearly 90dB.

An important factor found during the development of the experiment, was the fact that audibility of the signals was highly dependent on the frequency spectrum of background noise as well as the signal. The importance of this factor was also supported by literature, e.g., regarding ergonomic warning signal design (Patterson, 1990). It would be interesting to find out how large the advantage of automatic intensity adjustment would be if it is implemented using frequency dependent gain and not just the intensity of background noise. Future research should also direct to perception and attitude towards automatic intensity adjusted auditory signals in a more realistic situation where no direct comparison is possible. It should be studied in a similar way as SA, as the problem also has objective components in the form of detection rate or response to a signal, and subjective components in the form of perceived differences. Finally, for practical applications it is important how to make a trade-off between the different possibilities regarding auditory signal audibility. Several questions arise: to what extent should the signals be made more intense? How accurately should the design of signals take the background noise frequency spectra into consideration? Should a system like automatic volume control be implemented, and if so, in what form? Automatic volume control remains an interesting and unexplored field of study: regarding possible advantages and implications of automatic intensity adjustment for human-machine interfaces, a lot of work needs to be done.

6 General conclusions

The research objective of this report is to provide recommendations on how to manage the complete package of sounds within the truck cabin in the form of information and entertainment, communication, and auditory displays. More practical, in the first place, how can we realize a good balance between all in-cabin sounds? And second, how should we develop a method to compare different sound interface concepts. Recommendations in the form of guidelines are based on literature, on theoretical considerations, on expectations about future developments, on driver interviews, and on experimental findings. These recommendations elaborate on guidelines regarding HMI as developed by De Jong (2005). Findings regarding the two research questions are discussed below.

How should sound be used as part of the human-machine interface for supporting the truck driver?

A literature survey revealed that already extensive work was done in the field of warning sounds. As a basis, guidelines and specifications for in-vehicle auditory presentations for transport information and control systems (TICS) are provided in ISO 15006 (2004). The guidelines provide general technical properties of auditory signals, and give directions for choosing between different sorts of presentations. Because these guidelines are rather limited they are not sufficient for good signal design. There is sufficient literature, however, that gives more detailed insight into how to develop a complete range of warning signals, how to deal with background noise and the number of signals a human can learn (for example, Edworthy, 1996; Patterson, 1990). Regarding learnability, humans are capable of learning four to eight signals. In the latter case, good learning provisions have to be made. This is important especially when high priority signals are used; a collision warning should be recognized at once, since it will not function otherwise.

Many sources recommend developing a prioritization between the different auditory presentations. First of all, this should be done by designing the signals correctly. But second, especially with the ever growing amount of sounds, it is recommended to develop a prioritization for presenting the signals: a more important signal should prevent a less important signal to be played at the same time. Based on these literature findings, and on findings regarding current sound devices and future growth in the number of sound devices in trucks, an experiment was designed to provide insight into how drivers will deal with the effects of this growth in auditory stimuli. Results found were unambiguous; adding more auditory signals limits accuracy of SA, and counter measures in the form of prioritization and radio mute have a positive effect on SA and thus correct signal recognition.

Returning to the ISO (2005) guidelines, it is recommended to implement automatic volume control to maintain a constant level of audibility. Research on this area is lacking however. An explorative study and recommendations in literature indicate that such a system has benefits. The advantages are highly dependent, however, on frequency spectra of both background noise and signals. If frequency spectra of noise and signals are sufficiently different, automatic volume control is not nescesarry.

To finish the topic of within truck cabin sounds, a special category of warning signals that needs to be mentioned are incremental warnings. These warnings increase the perceived urgency incrementally in correspondence with the urgency of the situation. This can be done by speeding up the tempo or increasing pitch jumps within the signals. Only little research has been done so far; the type of signal looks promising however, because of its analogy with events it can represent. A typical example where such a warning is implemented is the parking help device. When parking, a signal is presented of which the perceived urgency is increased when the vehicle moves closer to an obstacle. Further, development regarding Automatic Speech Recognition (ASR), for example for voice dialling, and "text to speech" technologies need to be observed as those may seem promising for future applications within the truck cabin. Yet there are some problematic issues connected to these technologies, for example "text to speech" does not sound sufficiently natural. ASR is technically problematic under irregular background noise conditions and other disturbances, like the radio in a truck.

Which method is best suitable to compare different sound management concepts?

The experiment designed is aimed towards the influence sound has as part of the HMI on the truck driver, and not so much as the complete user interface of the truck, nor is it aimed at driving performance in specific traffic situations. Because of this, and the added complexity of a real life or simulator environment, scenarios were used made up of small sound supported slide-shows depicting traffic situations. Both the SAGAT and SART method were used in the experiment. This was done because SAGAT provides more insight into actual SA, whereas SART can be viewed as a measure for perceived SA. The effects found were robust, and were in correspondence with literature (Patterson, 1990; Edworthy & Adams, 1996), indicating high experimental validity. Thus, the method using small slide-shows looks very promising for relatively fast and cheap research, not only regarding principles within the sound interface, but possibly also for other display changes. Improvements can be made by fine-tuning the SA measures specifically for this research method. Further, it would be interesting to verify the results in an experiment having higher environmental validity like a simulator. In the end, the performance in real driving situations must be monitored, of course, before definite conclusions can be drawn.

To conclude, literature as well as research findings provide an extensive basis for sound management and a complete range of auditory displays; recommendations regarding these can be found in appendix C. Although much is known, there still is room for future research: regarding signals, as well as interaction between signals themselves and other modalities of the truck's human-machine interface. Both literature and the experiment done for this project shows that sound management has significant benefits for driving safety. Hopefully, this report can assist engineers within DAF trucks on the development of future sound interfaces.

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Downloaded for experiment:

Navigational messages: http://www.tomtom.com/plus/services/voices.php downloaded at 21-01-2007

Pictures highway in Germany: http://www.thuerstein.de/ downloaded at 21-01-2007

Abbreviations

ACC	Active Cruise Control
CB	Citizen Band radio
DIP	Digital Instrument Panel
DTS	DAF Telematic System
FCW	Forward Collision Warning
FCA	Forward Collision Avoidance
HMI	Human Machine Interface
LDWA	Lane Departure Warning
OD	Object Detection
OEM	Original Equipment Manufacturer
RPM	Revolutions per Minute
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique
SCW	Side Collision Warning
SNR	Signal to Noise Ratio
TICS	Transport Information and Control Systems

Appendix A

Elaboration on auditory signal properties, the different types of signals and signal design.

Index

APPENDIX A **49**

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Auditory displays

1 General signal properties

When using some form of auditory signals, four basic properties are important to keep in mind when designing or applying them:

- identification;
- discriminability;
- perceived urgency;
- localizability;
- Annoyance;
- Interference.

Research findings in the field of these four properties are mostly based on earcons; they are generally applicable, however, to the other two forms of auditory displays as well. The four properties will be discussed below. ISO recommendations provide some general signal requirements for audibility, to prevent startle reactions, and to prevent intensity levels becoming dangerous (ISO, 2004). The usable frequency spectrum should range from 400 to 4000 Hz for earcons and from 400 to 8000 Hz for speech messages. Signal detection rate should be as high as possible; usually a detection rate of 95% is demanded. The signal sound pressure level should be between 50 and 90 dB and its signal to noise ratio (SNR) should range from 5 dB up to 15 dB. It should however be noted that the SNR is a measure that lacks sufficient detail. For obtaining good audibility it is much more important to design the signal in such a way that all frequency components are within the appropriate intensity range (discussed later). To prevent startle reactions by a sudden signal onset (that results in the perception of a "tick" sound), the onset of the signals' sound pressure should range between 0.33 dB/ms and 1 dB/ms, depending on message importance. Because background noise fluctuates and hearing abilities differ, signal levels should be adjustable within a range of about 10 dB. Finally, recommendations are provided to determine which signal type to use depending on urgency, earcons being always suitable, and speech being recommended when a long term response is required. In practice, the automotive industry uses speech messages in their products mainly for navigation and traffic messages, information applicable for the middle and long term. Earcons or auditory icons are used for shorter term messages and to attract attention to a specific device. With the arrival of in-vehicle computers, speech could become a more important modality to present messages having high complexity.

1.1 Identification

A tonal signal must be easy to identify. Otherwise it loses its advantage over a visual signal. This means that signals have to be easy to learn and thus they need to have distinct different properties. To achieve this, the signal has to be appropriate as possible for the specific problem it represents; this can be solved by urgency mapping: as discussed before, perceived urgency of the signal should match with the urgency of the alarm cause.

Another important factor limiting identification of signals is the fact that people have only limited capabilities in remembering different abstract earcons. The sheer number of different alarms was found problematic in many hospital environments; it was found for instance that one operating and recovery room had 49 different alarms at its disposal (Edworthy & Adams, 1996). In another case ten or more alarms per patient on an intensive care ward were reported. For a six person ward, that meant a total of 60 alarms (Patterson, 1990).

Regarding successful recognition of these large numbers of signals, Edworthy and Adams (1996) reported a study in which recognisability was tested. Nurses and anaesthetists were assessed on their ability to identify the signals correctly. It was found that nurses could identify on average eight signals and anaesthetists only five signals. On the other hand, especially anaesthetists overestimated the number they could identify correctly, showing that self reported identification measurements should be used cautiously. These ever increasing numbers of earcons, as discussed here, were also found in aviation (Doll and Folds, 1986). One of the causes of this problem was the fact that manufacturers equip their products with auditory alarms, simply because it is possible (Edworthy & Adams, 1996). Looking more specifically into the number of signals that can be learned, Edworthy and Adams (1996) reported a study by Patterson who found that up to five or six alarms were easily learnable. Beyond this limit, it becomes much harder to learn the signals. These results are in accordance with findings that humans' capability to remember arbitrary unrelated items of information reaches from five to nine. An example of the difficulty of learning earcons, are the alarms from emergency vehicles. Although everyone knows that the sound originates from an emergency vehicle, identifying them as coming from police, a fire truck or an ambulance is much more difficult for most people. This happens in spite of the fact that people start learning them at a very young age, and hear them on a regular basis.

1.2 Discriminability

Non speech messages, if designed improperly, can easily be confused, especially under high workload or stress. An example involving a high risk of confusion was described by Doll and Folds (1986), regarding the F16 jetfighter, production blocks 01 and 05, auditory warning system. The airplane's warning system used two auditory signals that both had a fundamental frequency located around 800Hz, one signal to indicate excessive "Angle Of Attack" and one signal for "low altitude/terrain". If these two tones were confused, it could have lead to disastrous consequences: one condition can be corrected by increasing airplane pitch, while the other condition can be corrected by decreasing pitch. This shows us the importance, especially for highly critical warnings that require immediate action to be taken, that clear distinguishable warnings are a necessity. To achieve this, the most important properties for giving earcons a clear distinctiveness are the temporal characteristics and the use of multiple harmonics (Doll, 1986; Patterson, 1990).

1.3 Urgency

Perceived urgency can be varied by adapting the technical properties of the warning sound, like tempo, fundamental frequency, repetition units and inharmonicity (Edworthy et al., 1993). Especially tempo, shorter pulse to pulse (a pulse is the basis that a signal is made from, see figure 12) times, has proved to be highly influential on perceived urgency (Hellier, 1999). In this way the sound can be matched to a certain level of urgency, a process which termed "urgency mapping" (Edworthy, 1994). Urgency mapping is considered an essential precondition for a successful implementation of auditory warnings. The effect on perceived urgency for a number of pulses and bursts (a burst is made from a number of pulses, see figure 12) properties can be found in tables 13 and 14; for some properties table 15 shows to what extent urgency is effected.

Table 13. Effects of pulse characteristics on perceived urgency (Edworthy & Adams, 1996).

Parameter	Direction of Effect
Fundamental frequency	High > low
Harmonic series	Random / 10% irregular > 50% irregular > regular
Delayed harmonics	No delayed harmonics > delayed harmonics
Amplitude envelope	Regular / slow onset > slow offset
> More urgent than / Equally urgent	

Table 14. Effects of burst characteristics on perceived urgency (Edworthy & Adams, 1996).

Parameter	Direction of Effect
Speed	Fast > moderate > slow
Number of repeating units	4 > 2 > 1
Rhythm	Regular > syncopated
Speed change	Speeding up > regular / slowing
Pitch contour	Random > down / up
Pitch range	Large > small > moderate
Musical structure	Atonal > unresolved > resolved
> More urgent than / Equally urgent	

Table 15. Relationship between warning parameters and urgency (Hellier &Edworthy, 1997).

Warning Parameter	Increment to increase urgency		
	50%	Double	Treble
Pitch	*2.8	*6	*17.4
Speed	*1.3	*1.6	*2.2
Repetition	*2.2	*4	*8.9
Inharmonicity	*28.5	*307	*8773

Momtahan (see Edworthy & Adams, 1996) showed the largest effect on perceived priority to come from loudness. However, loudness could be perceived different under background noise: a signal 5 dB above background noise sounds less loud compared to a signal 20 dB above background noise. There was no correlation found between alarm importance and identification speed. Another study revealed that it was less likely for the more important warnings to be recognized correctly (Momtahan et al. 1993). This is probably caused by appearing less often or appearing hardly at all, compared to not-so-urgent signals. The work of De Jong (2005) within DAF trucks confirmed earlier work by Hellier (1999), that tonal height, or pitch, was considered only of limited importance to perceived urgency. It was also concluded that dividing a signal into bursts results in a lower perceived urgency: lower urgency was realised when a longer break between the signals was used. This effect can be of good use for signals needing a variable urgency rate, as is needed for the Active Cruise Control system. It must be noted that the differences in perception were found by direct comparison between the signals. In a real-life situation, however, the signals will be presented at significantly larger time intervals compared with laboratory studies. In that case, direct comparison of the auditory signals is not likely to happen.

There are cultural differences regarding the perceived meaning of warning sounds, although some sounds and sound properties are judged remarkably similar across cultures (Edworthy & Adams, 1996). Siren like sounds produced the most consistent meaning in a study using participants from Germany and Japan; probably because of their more universal usage compared other warning signals. Across all signals, the perceived "tendency for action" was rated very similar.

1.4 Localizability

As humans can detect the direction where a sound comes from, this provides possibilities to provide extra information within the auditory signal. Directional signals could be considered as a further subcategory of auditory signals: directing attention to the source of the sound. Humans are specifically good in locating sounds to the left and to the right of themselves. Locating sounds in front and to the rear of them is more difficult. The same goes for sound sources above and below them. The human has several methods for localizing sounds, some function good for lower frequencies, others for higher frequencies. However, for the frequency region in between, located around 1 kHz, it is more difficult to correctly detect direction. This is the very region where our hearing is most sensitive, located in the middle of the range usable for auditory signals. Edworthy and Adams (1996) noted that a lot of auditory warnings on hospital equipment make use of harmonic frequencies located exactly in this area, making them very hard to localize. A possible solution to this problem is to give the sound complex acoustics instead of relying on only one intense harmonic (Edworthy & Adams, 1996) and have the fundamental frequency outside the range for which it is difficult to detect direction. It was found that good localizable signals can improve response speed and result in more correct responses (Bliss, 2000), indicating the importance of designing for good localizability.

Research conducted by Ho and Spence (2005) showed the effectiveness of warning sounds containing direction information, spatial predictive warning sounds, in capturing the drivers visual attention into a desired direction. Their study compared tonal and speech messages. It was found in a series of laboratory experiments that vocal direction indications, the spoken word "front" or "back", results in 100 ms faster responses compared to a spatial warning, a car horn originating from a certain direction. A limitation of the study is that background noise was not taken into account; it is widely known that vocal signals are highly vulnerable to background noise. Further, the message length will increase considerable for other than 90° angles, for instance "rear, left", eliminating the response time advantage. Another implication is the location of the "back" speaker for the experiment; it was located on the rear left-hand side. It was argumented that it should prevent potential front-back confusions, but it could possibly add a "left" confusion. Especially in a practical implementation where it is possible that a collision warning system also detects the left and right hand side of a vehicle this could result in misinterpretations. When using a tonal signal as a warning, people can detect directionality of 45° to 30° easily (Bellotti et al., 2002). Bellotti noted another implication to deal with when using directionality as a warning queue: the Franssen effect. Consider two directionally different sound sources; the first source emits a warning tone. After a certain amount of time, the first source gradually stops, while the second starts emitting the same tone. Experiments show that people continue to perceive the tone as originating from the first source, a critical effect when directionality is an important cue, for instance with collision warning systems. As humans are more sensitive to discontinuous events rather that to continuous events. Bellotti et al. (2002) made the tone discontinuous by repeatedly turning it on and off, as a solution to this problem. This in effect masked the signal for short periods of time, in the process also improving perception speed and localization.

1.5 Audibility

For a warning sound to be effective, it has to be heard. This seems to be very logical and easy to deal with, but many problems are related to audibility problems. For instance, a study by Momtahan (1993) showed the risks of having different independent systems using warning sounds. It was found that several warning sounds used in an Operating Room and an Intensive Care Unit had the risk of being masked by other warning sounds. Edworthy & Adams (1996) have found similar problems: the intensity level of one alarm could also cause masking of another less intense alarm sound. A lot of problems were also found in the aviation field. As a reaction on many pilot complaints, a large amount of studies have been carried out regarding auditory warning signals in aircraft. It was found that many auditory warnings did not operate on an appropriate sound level, many components falling below the auditory threshold and others above the appropriate sound levels (see figure 10). If only few components are audible there is a larger risk that these also become masked. On the other hand, components that are too high can cause hearing damage, or can disrupt communications, especially when a warning sound is continuous.

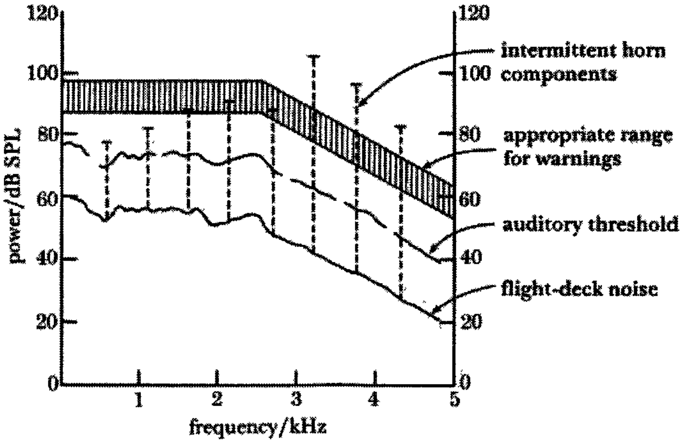

Figure 10. An example how a warning signal should <u>not</u> be designed, most horn components should be located in the "appropriate range for warnings, not above or below that range (Patterson, 1990).

The solution to the masking problem is to carefully study the background noise and take the results into account when designing a signal. As Patterson (1982) mentioned, quoted by Edworthy and Adams (1996, p. 131): "It (the background noise) can have a million times the acoustical power of a signal, and yet the signal remains perfectly audible if the bulk of the signal power occurs in a different frequency range then the spectrum of the noise". Humans do not hear the separate pitch for each peak in the spectrum of a (warning) sound (see figure 11); in fact, the pitch we hear is the pitch corresponding to the fundamental frequency within the sound. The more components a signal has in the appropriate range, the smaller the chance of masking to occur, and, if harmonics are used, perception of the signal remains the same. It is advised to have at least four frequency components within the appropriate frequency range.

For determining the correct intensity range, first the frequency specific auditory threshold needs to be determined. This is the level above background noise, depending on frequency, at which a sound is detected 50% of the times. Patterson (1982) developed an auditory filter model as a basis for predicting the auditory threshold. The results for an airplane can be found in figure 10. As a crude rule of thumb it can be said that the auditory threshold is located 15dB above background noise level. When the auditory threshold is known, the appropriate range for warnings is located 15 to 25dB above it. As a note, this is the appropriate range for warnings; for other information or attention signals this range will be considered too loud, especially when the sound is often presented.

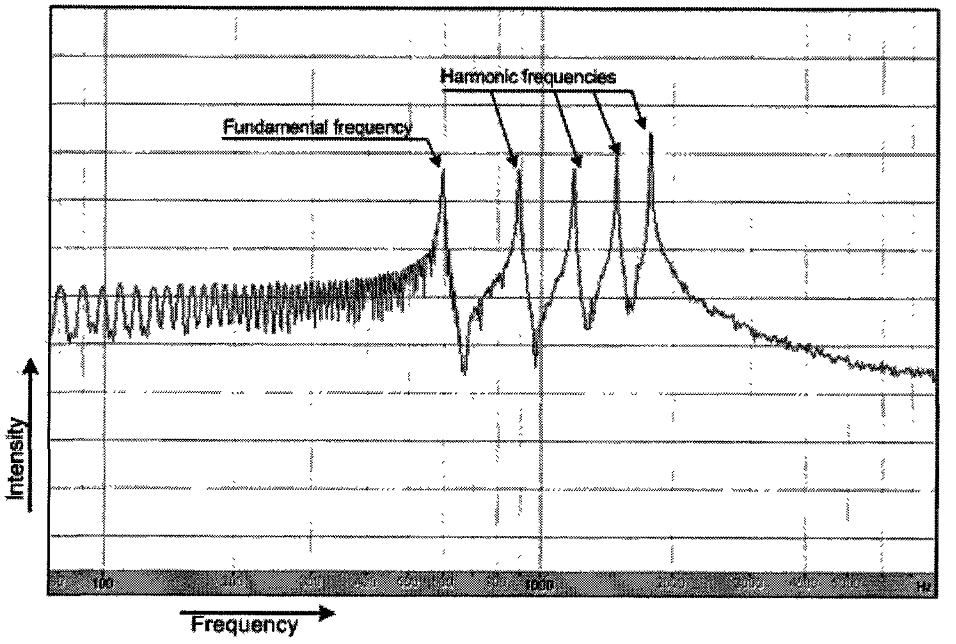

Figure 11. Frequency spectrum of a warning signal used in a truck. The five peaks should be located within the "appropriate range for warnings".

2 Earcons or tonal signals

As already said, the use of earcons has specific implications that need to be taken into account when designing them. These implications are primarily related to the fact that a tonal signal has no intrinsic meaning. As ISO (2005) guidelines state, a tonal signal is intended to release a specific driver's behaviour. This intended behaviour should be explicitly formulated by the designer; this comprehensibility should be measured to ensure that the desired response is achieved. A procedure regarding testing of compliance is specified in ISO 15006 (20050, additionally some general recommendations for signal design for appropriate urgency are provided, which are based on findings as discussed in paragraph 1.3:

- Short-term message: Sweeping sounds, bursts of sounds, alternating tone pitch, fast rhythm of dissonance.
- Medium-term message: Patterns of segments with constant pitch, the shortest at least 0,3 s.
- Long-term message: Two-times chimes, high-low recurrent followed by a verbal message or visual display.

Some specific implications to deal with earcons are discussed in the following paragraphs, including an example of a successful designed sound interface.

2.1 Tonal signal design: the Sea King helicopter

The Sea King helicopter in service with the UK military traditionally used very few auditory warnings, but besides the risk of missing visual warnings, increased night flying made an auditory warning system essential (Edworthy & Adams, 1996). The helicopter uses three levels of visual warnings: red when immediate action is required, amber for immediate awareness, and green for information. When night flying began to occur more frequently with the introduction of night vision goggles, the colour coding became useless and research for implementing auditory warnings was initiated.

To limit the number of necessary warning signals it was decided to use the same idea as the color coding described above, a single distinct auditory warning for each of the three priority levels. For the highly important "red" warnings, however, more variants were needed conveying a more specific message. For the green and amber priority levels, the additional information regarding the specific problem was provided by either a spoken message, or a visual display, or both. This way, the total number of required warnings was kept to eight, which is within the learnable range. The signals were constructed according to the guidelines provided by Patterson (1982) and kept the required intensity levels in mind under influence of helicopter background noise. How to deal with background noise was discussed in paragraph 1.5, explaining the signal design methods as used and developed by Patterson.

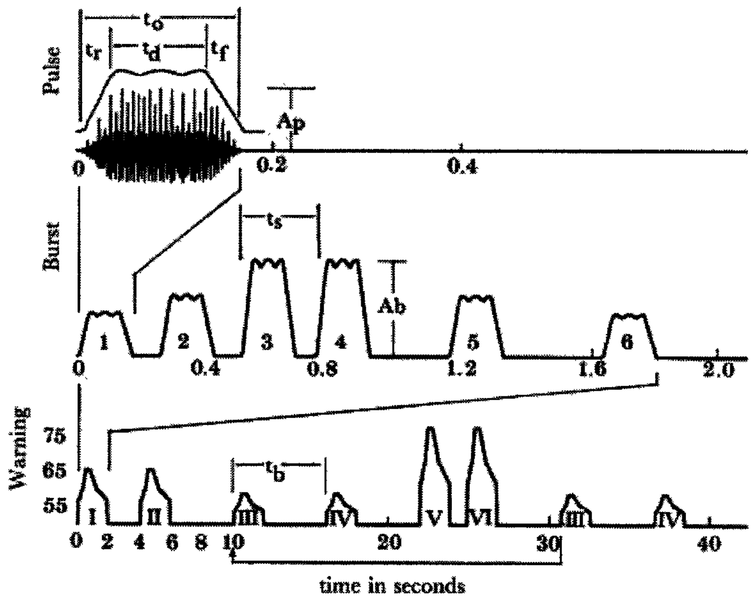

Figure 12. Warning signal design according to Patterson (1990)

The warning is build up out of several bursts having different intensity; a burst consists of a pattern of pulses. The signal is build up out of a basic pulse which has a waveform unique to a particular warning. This pulse is used to construct a burst, a temporal pattern of pulses, with variations in pulse amplitude, the first pulses somewhat lower to avoid startle, giving the warning a specific rhythm. The temporal pattern can be used to manipulate the perceived urgency of the warning. The complete warning can have a pattern like shown in the bottom row in figure 12, a temporal pattern of bursts varying in relative amplitude. First, the signal should be brought under attention of the user using a moderate amplitude level. Assuming the user has heard it, and is working on a solution, the next bursts can have a lower amplitude level to avoid irritation. If nothing has been done after some time, the bursts are played at their highest level to indicate that the problem still persists.

For testing on learnability, the signals were presented to a population of pilots and to a population of civilian defence personnel using a self paced cumulative learning paradigm (Edworthy & Adams, 1996). A warning signal was presented and had to be named by the participant. Than, two warnings were presented which the participant had to name, the one already learned plus a new one. Then a third warning was introduced, and so on. It was found that civilian personnel responded very much in the same way as the pilots did, although their performance was a little lower. Both groups reached 95% accuracy, however. The fact that both groups showed similar capabilities provides opportunities to make testing more easy and cheaper.

The design method developed by Patterson (1990) was used not only for the Sea King described above, but also for other helicopters, as well as for design directives concerning hospitals, for the Civil Aviation Authority, and for British Rail Research.

3 Speech messages

Although speech is considered to be easy to understand, it has some specific problems that need to be reckoned with: confusion between different communications, a bigger risk of masking, and mistakes in interpretation are some of them (Wickens, 1998). Regarding the use of speech, ISO (2005) provides some basic guidelines. Speech should be used when there is sufficient time to listen to the full message before action is required. The message length should be limited, not longer than 5 information units ("Close to Eindhoven" is considered one unit). Higher urgency messages require less information units to obtain a sufficient response time. In case of complex speech information some basic directives are:

- sequencing the units of information in order of potential relevance;
- providing key words, prosodic cues and highlighting;
- providing redundant visual displays;
- providing means for the driver to request that the message be repeated.

Nowadays, in-vehicle vocal messages can be found in the form of traffic messages (either by radio or another device) or route guidance messages. Vocal route guidance messages are preferred over visual displayed route guidance because it reduces drivers' workload (Tijerina et al., 2000; Green, 1994). In general, sampled speech is more intelligible than synthetic speech, but it has a design limitation: for instance, recording all street names (and landmarks) is difficult and costly. Recent technical breakthroughs are making synthetic speech systems easier to understand and lower in cost making them interesting for future use. These systems have better possibilities to communicate extra information like street names and landmarks since not every specific name has to be recorded advance (Tijerina et al., 2000). Synthetic speech could also be an opportunity for mediating the risk of textual message reading while driving, as mail messaging systems are becoming more frequently used in commercial vehicles.

3.1 Navigation devices

Turning to the topic of navigation messages, the way a speech message is formulated is important for recalling the message. According to Tijerina et al. (2000) and Burnett (2000) people perform better when context rich messages are used in navigation systems, like mentioning of landmarks within route guidance messages. Landmarks are naturally used for navigation purposes. Although landmark databases exist, this information is conspicuously absent in current route guidance systems. Fleming et al. (1998) found a number of effects regarding memory that are important to consider for the design of speech messages. When a message gets longer, traffic messages for instance, drivers mostly recall the parts that seem the most important. The cause of congestion, an accident for instance. People focus more on messages that are considered important to them like a message mentioning the specific highway they are driving on. Further, the first and last items of a message are also remembered more correctly compared to the information units in the middle of a message. Certain parts of traffic messages seem to be harder to recall, however those arte important to perceivers, like direction of the congestion or the length. These implications with message recalling show clearly the limitations of human short-term memory. Green (1994) developed guidelines for driver information systems like navigation devices. A system with three types of messages was recommended: an "early" message, a "prepare" message and an "approach" message. Further, it was advised to provide means to (de-)activate the auditory messages and to provide a function to repeat the last message that was presented. A more recent industry overview (Llaneras, 2002) showed that a majority of the systems available already had such a repeat function. OEM Navigation systems were mostly integrated with the automobile speaker system and incorporated a radio mute function, lowering radio volume when a navigation message was presented. These provisions were less common found in aftermarket equipment. The possibility that muting could annoy drivers was mentioned, but not investigated.

Appendix B

Experimental design: stimuli and questionaires.

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APPENDIX B **60**

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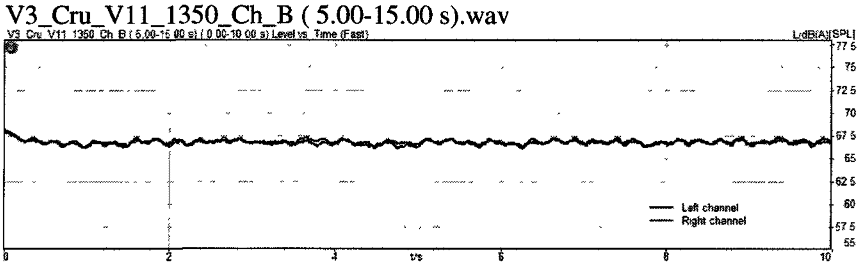
1 Sounds used

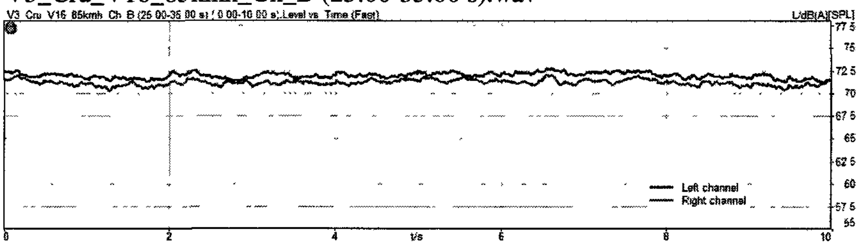
Sounds were recorded within the truck cabin using in ear microphones (type: HEAD BHM III). Below, oscillograms are shown for all auditory signals and background noise conditions used. Vocal messages and radio are not shown.

Backgroundnoise

- V3_Cru_V11_1350_Ch_B (5.00-15.00 s).wav

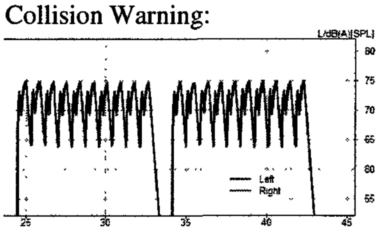


- V3_Cru_V16_85kmh_Ch_B (25.00-35.00 s).wav



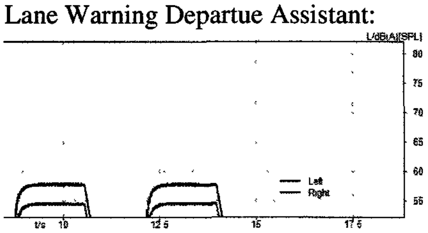
Primary driving task related signals

- Collision Warning:



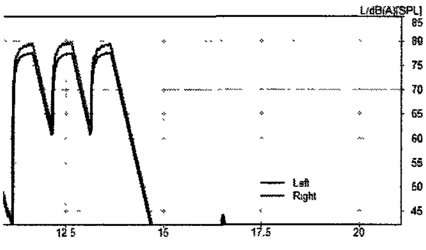
ACC LCW rechts.wav (source: de Jong, 2006)
ACC LCW links.wav (source: de Jong, 2006)

- Lane Warning Departue Assistant:



LDWA rechts.wav (source: de Jong, 2006)
LDWA links.wav (source: de Jong, 2006)

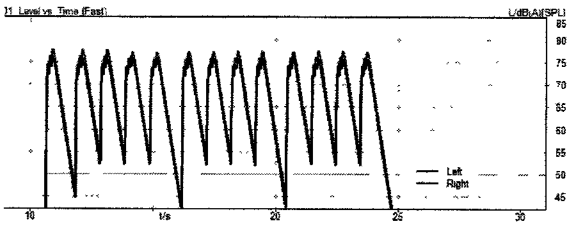
- Red.wav



Other signals

Secondary driving task related signals

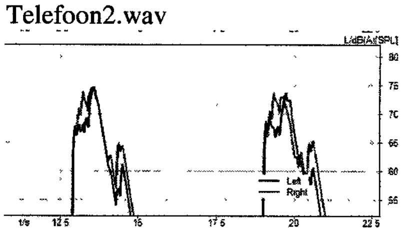
- DirInd.wav
- Yellow.wav



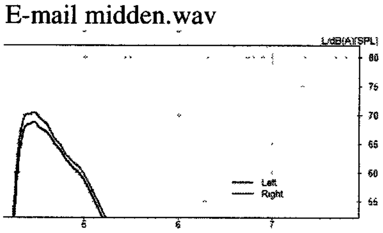
- Navigatie berichten (source: http://www.tomtom.com/plus/services/voices.php downloaded at 21-01-2007):
  Ga rechts op de rotonde.wav
  Neem de tweede afslag links.wav
  Ga rechtdoor.wav
  Houd rechts aan.wav
  Neem de afslag.wav

Driving irrelevant signals

- Telefoon2.wav



- E-mail midden.wav



(Source: Microsoft Windows XP, notifywindows.wav)

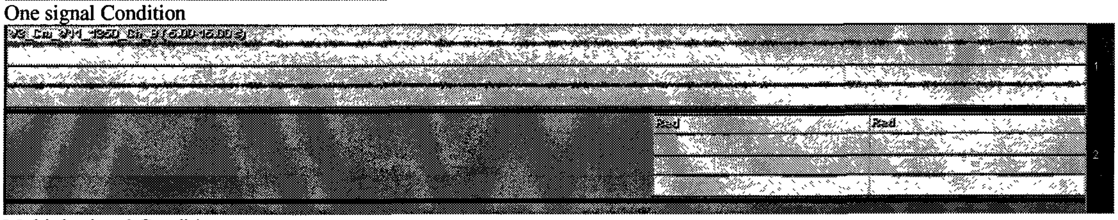
- Radio:
  radio spraak m021.wav
  radio muziek m011.wav
  radio muziek m021.wav
  radio spraak m022.wav
  radio muziek m012.wav
  radio muziek m022.wav
  radio spraak m011.wav
  radio spraak m012.wav
  radio muziek m031.wav
  radio muziek m032.wav
  radio muziek m031.wav
  radio muziek m041.wav

2 Scenarios

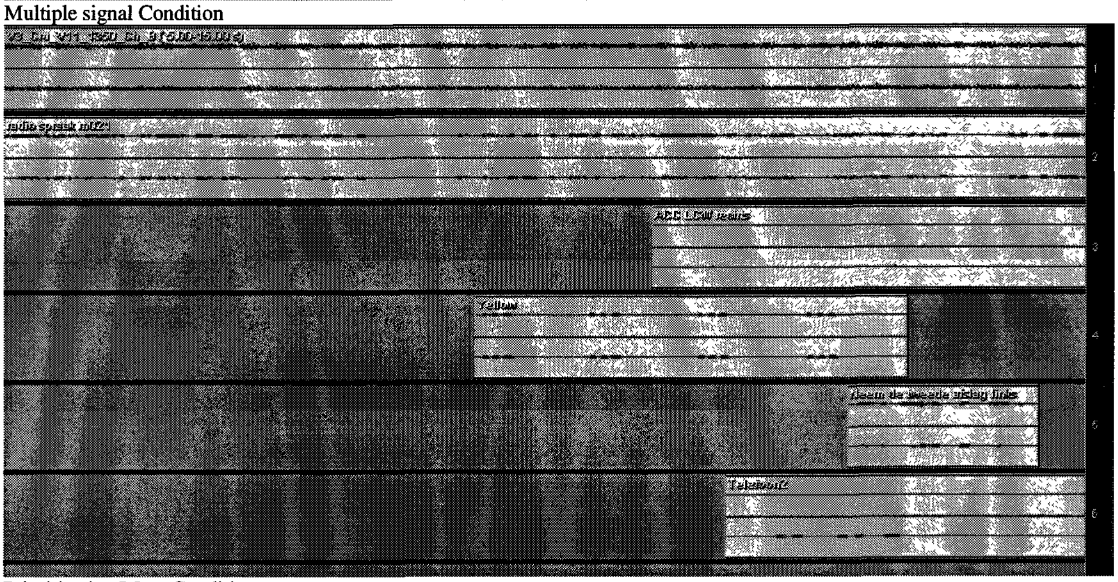
Each scenario consists of two pictures and a combination of the sound files mentioned above. There are six visual scenarios each having three sound conditions resulting in a total of 18 combinations. The design is shown below: two pictures for each visual scenario and oscillograms showing relative amplitude as a function of time for the sounds used each condition. The combinations that are shown consist of a combination of the sounds of which the properties are shown in more detail above. Each sound fragment is 10 s, the second picture was show after 6 s and the primary driving related signal was played 0.5 s later.

Scenario A

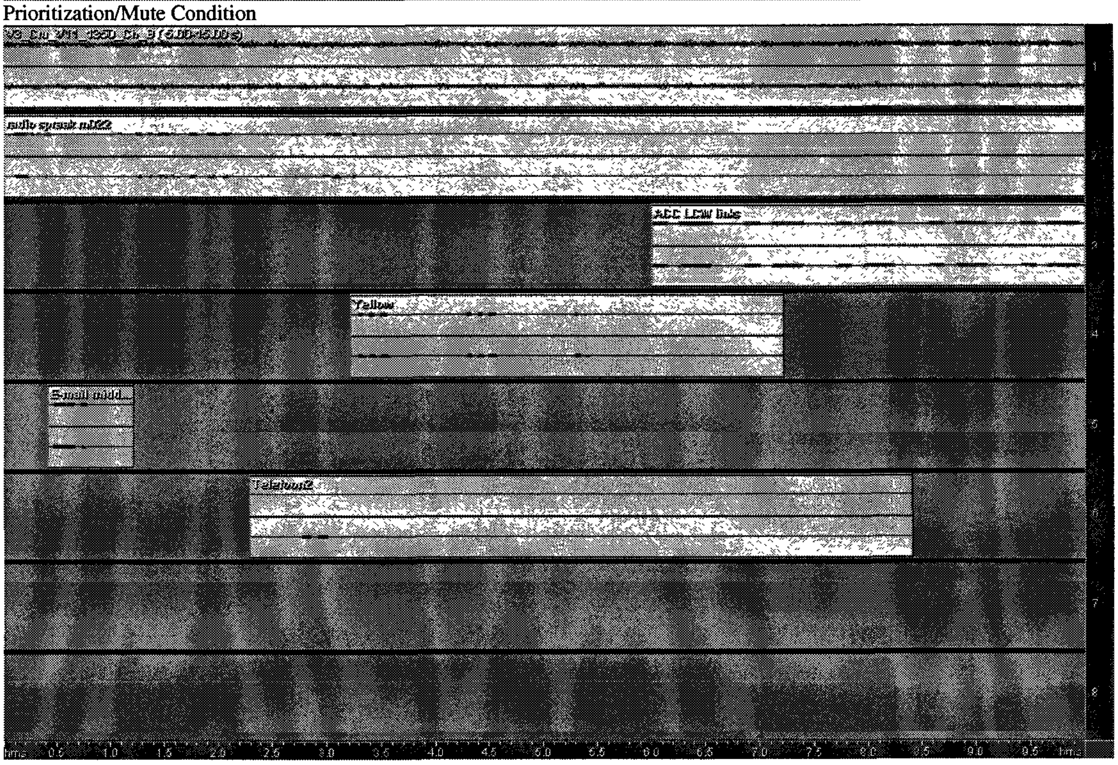
One signal Condition



Multiple signal Condition

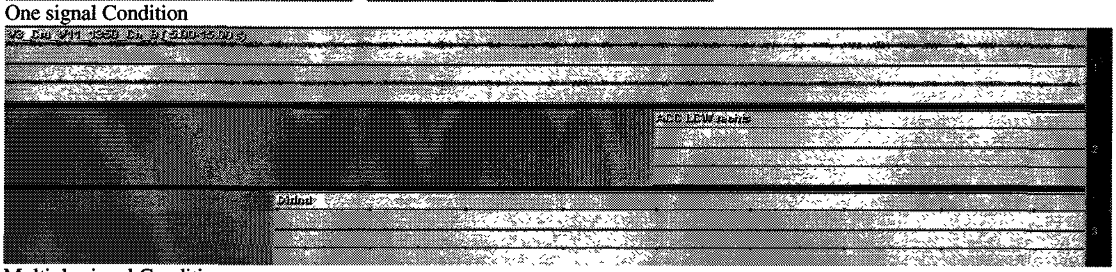


Prioritization/Mute Condition

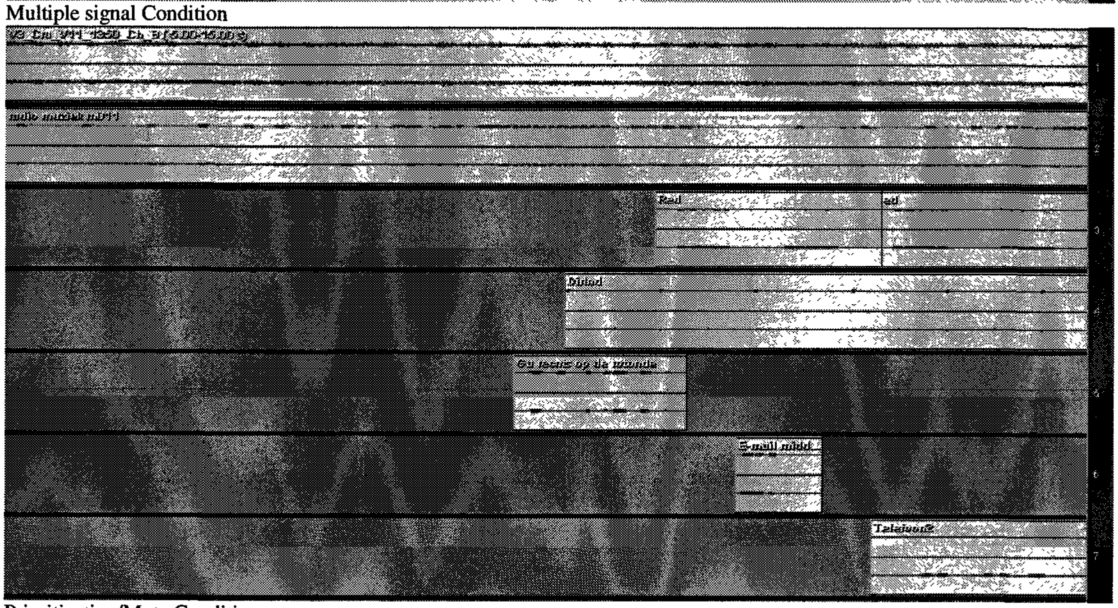


Scenario B

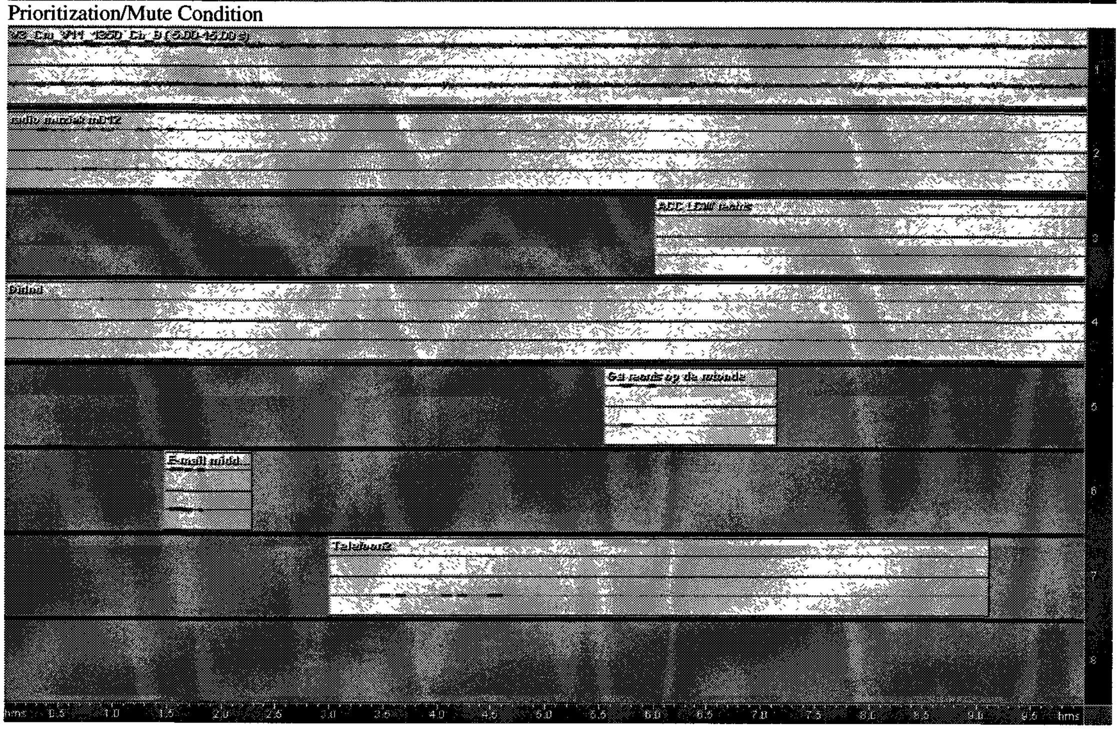
One signal Condition



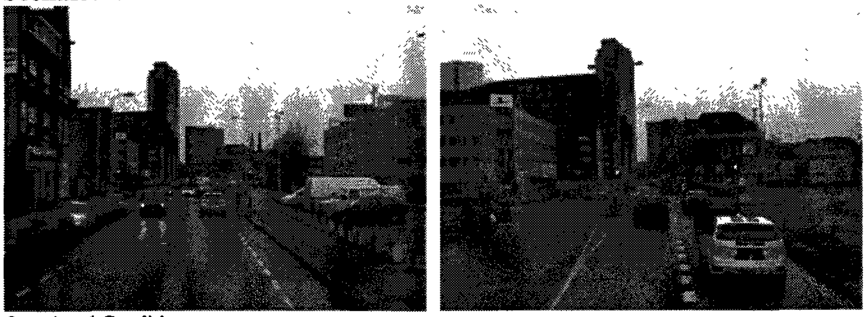
Multiple signal Condition



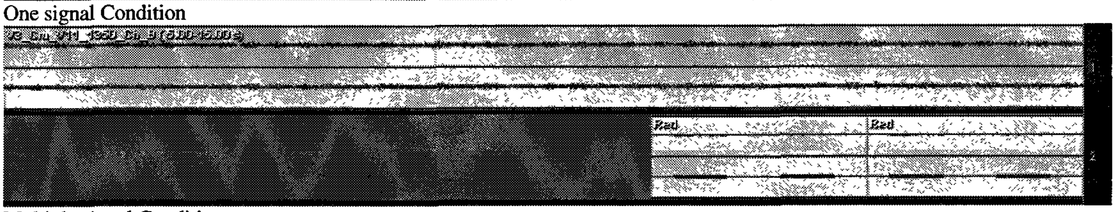
Prioritization/Mute Condition



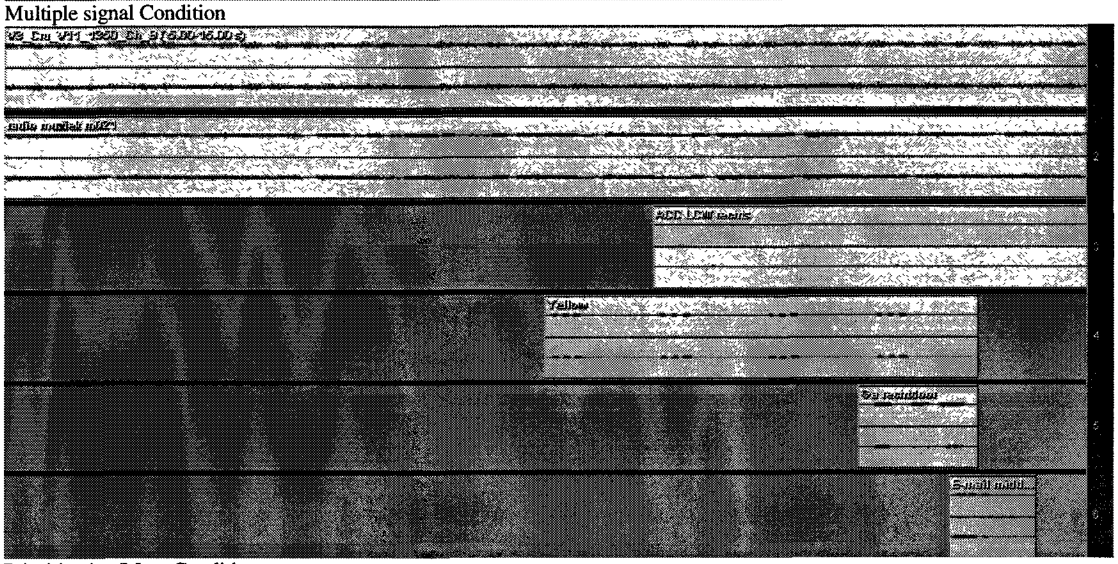
Scenario C



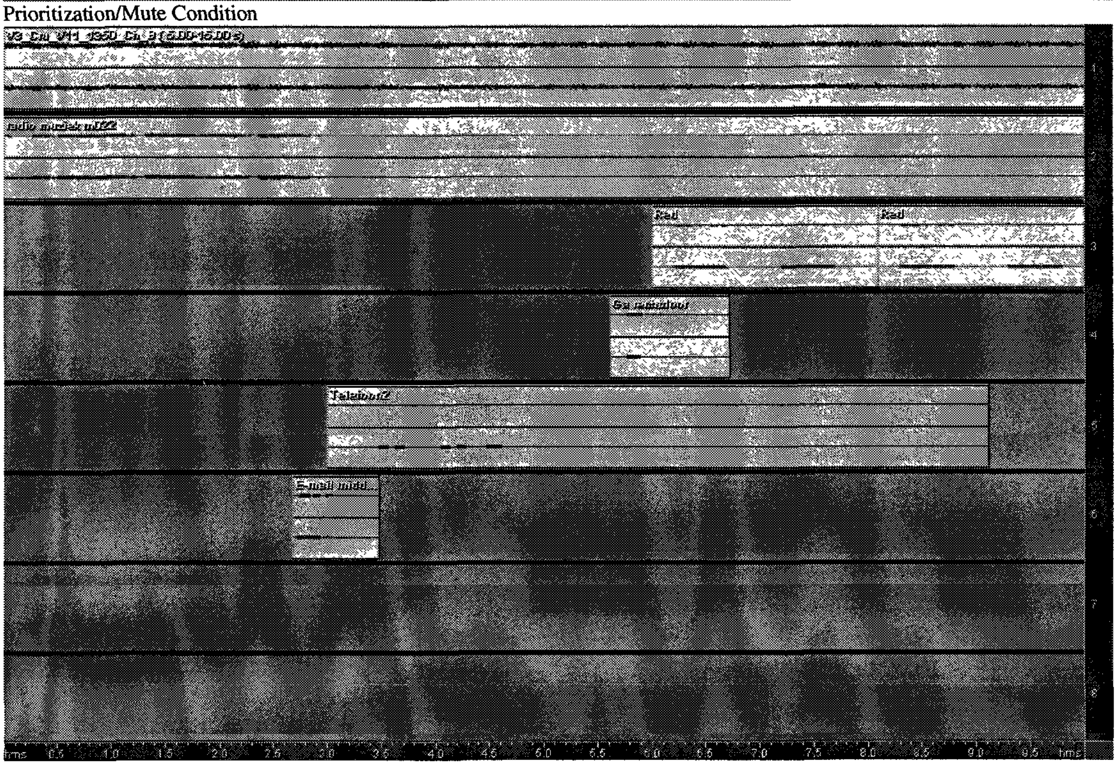
One signal Condition



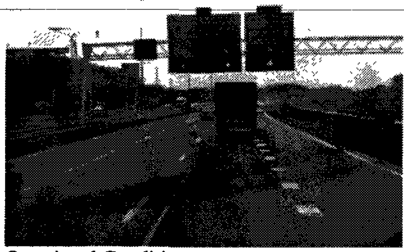
Multiple signal Condition



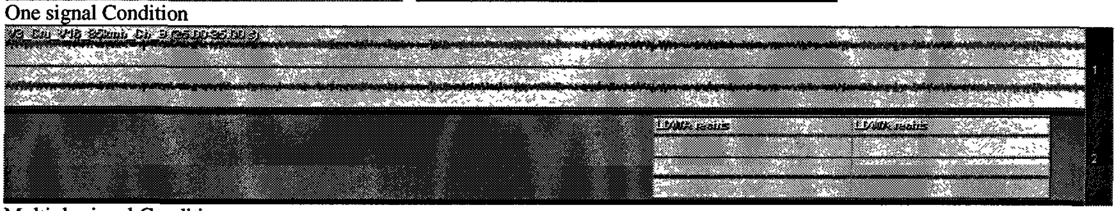
Prioritization/Mute Condition



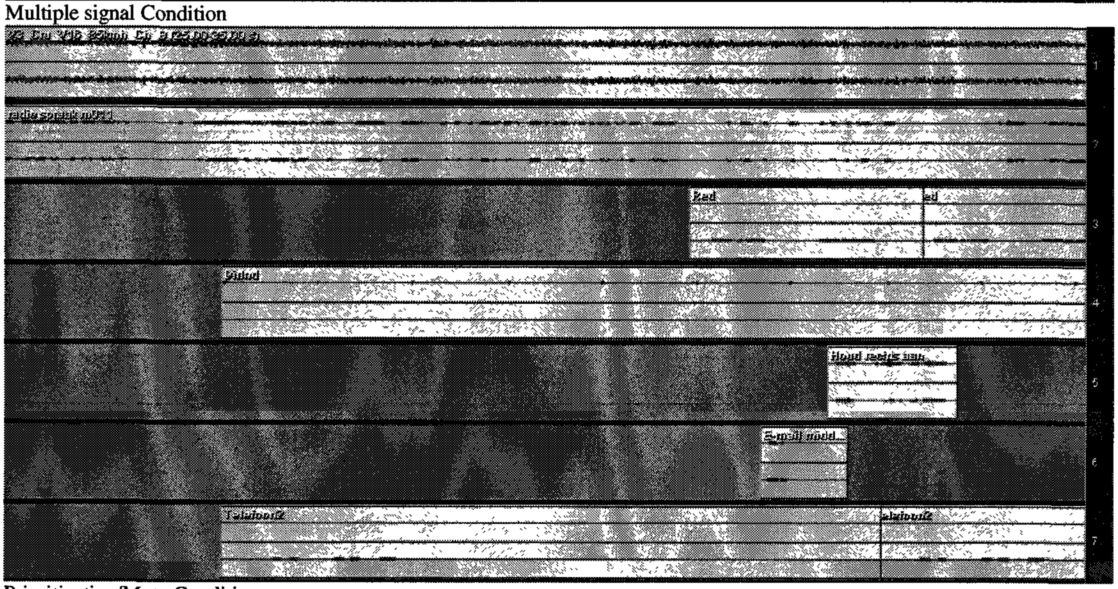
Scenario D



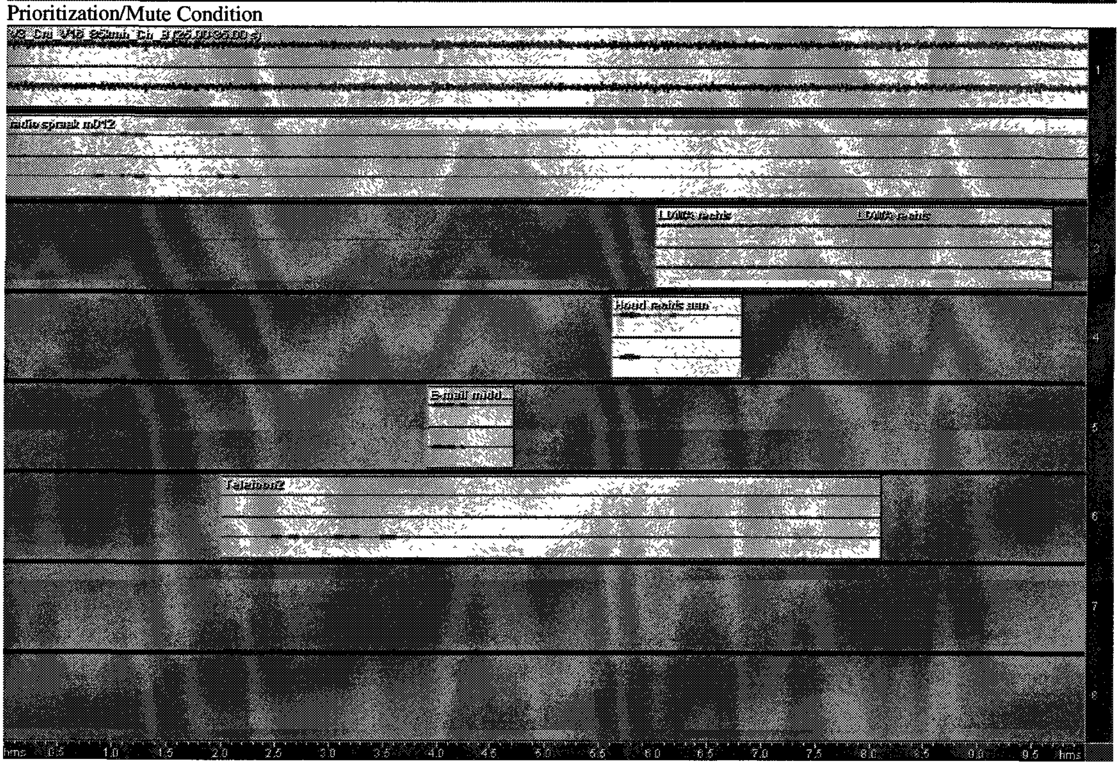
One signal Condition



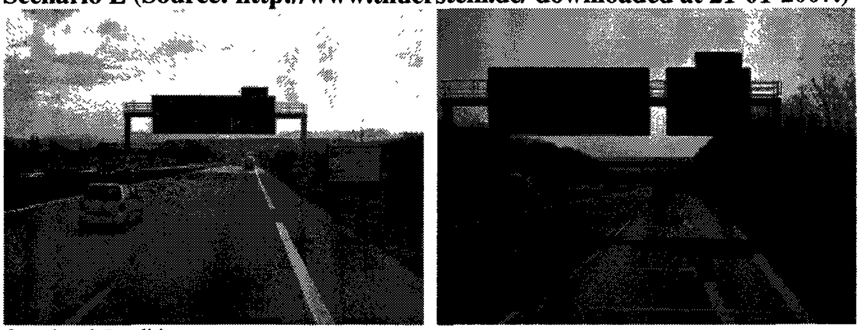
Multiple signal Condition



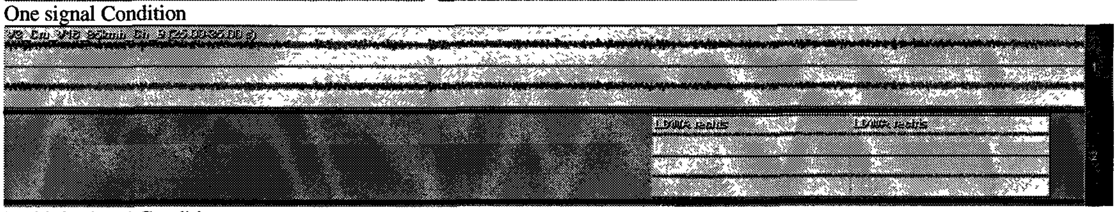
Prioritization/Mute Condition



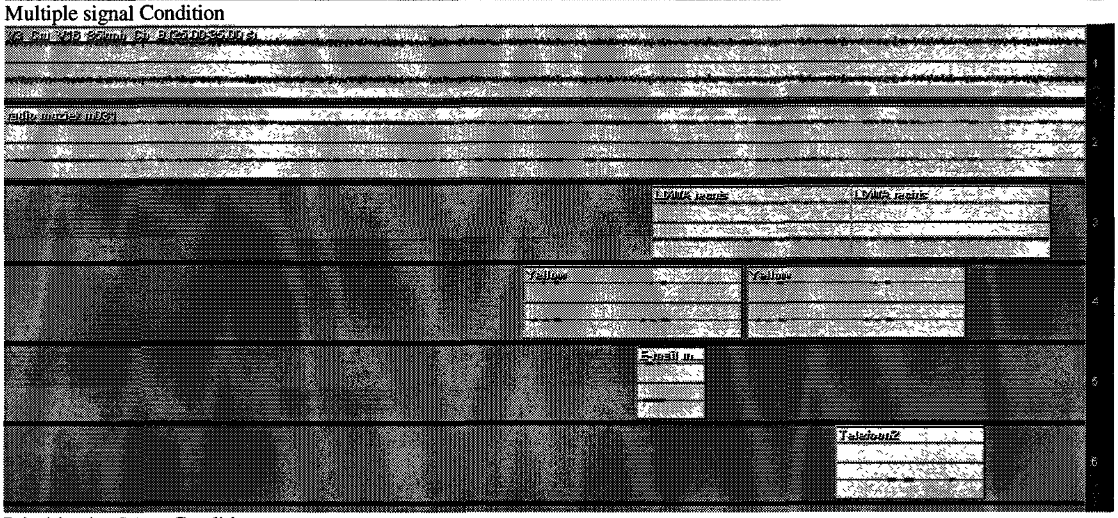
Scenario E (Source: http://www.thuerstein.de/ downloaded at 21-01-2007.)



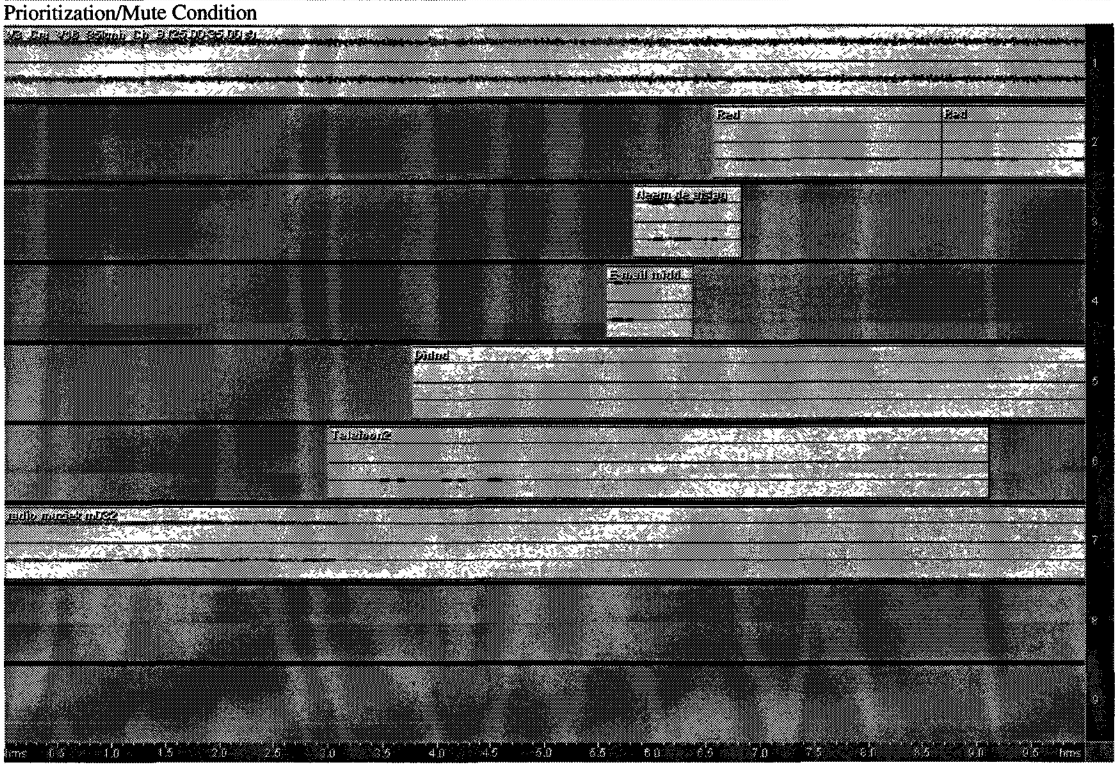
One signal Condition



Multiple signal Condition

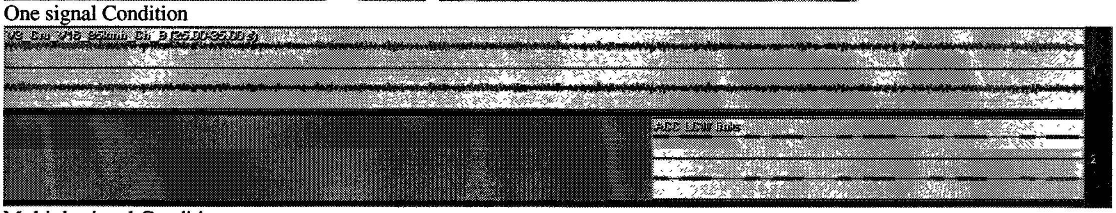


Prioritization/Mute Condition

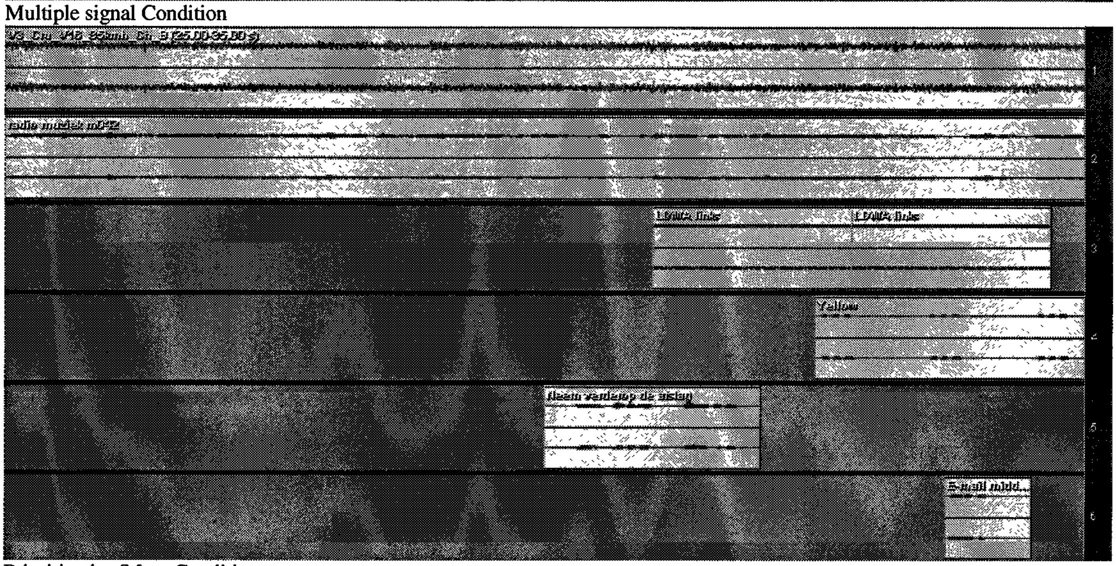


Scenario F (Source: http://www.thuerstein.de/ downloaded at 21-01-2007.)

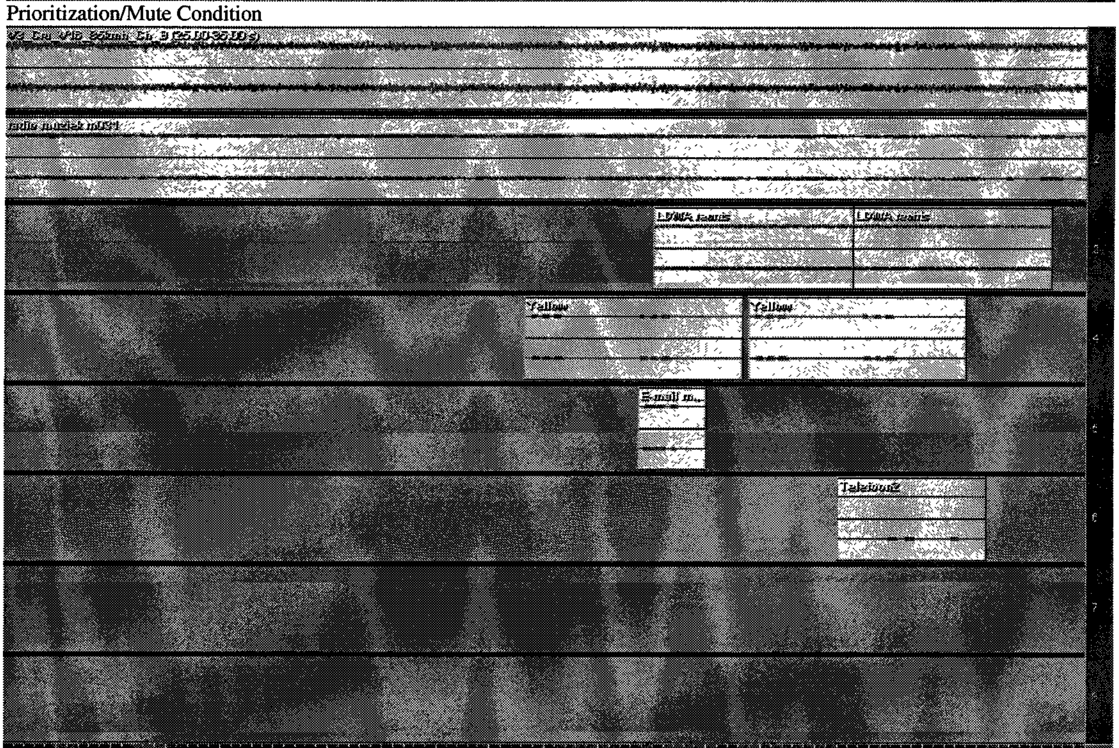
One signal Condition



Multiple signal Condition



Prioritization/Mute Condition

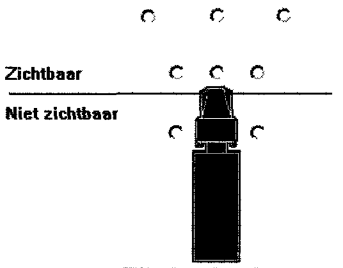


3 Questions

Experiment 1: SAGAT Queries

Geef alstublieft aan welke van onderstaande zaken van toepassing zijn op de verkeerssituatie zoals u die zojuist heeft mee gemaakt. U kunt net zo veel mogelijkheden aanvinken als u wilt.

1	Geef in onderstaande afbeelding aan waar overige verkeersdeelnemers (rijdende voertuigen, fietsers, of voetgangers) zich bevinden welke een gevaar kunnen gaan opleveren. Doe dit door de betreffende rondjes aan te klikken.



2	Geef aan welke van de onderstaande zaken u heeft waargenomen
○ Geparkeerde voertuigen	○ Voetgangers
○ Tegemoet komend verkeer	○ Fietsers
○ De staat van het wegdek is slecht	○ Een rotonde
○ Wegopbraak	○ Een kruispunt
○ Verkeerslichten	○ Een zijstraat
○ Er is iets ernstig mis, ik moet stoppen	○ Iemand belt me
○ Er is iets mis, maar ik mag verder rijden	○ Knipperlichten vergeten
○ Er komt een e-mail bericht binnen	○ Ik wijk te veel uit naar rechts
○ De radio staat aan	○ Ik wijk te veel uit naar links

3	De staat van de omgeving is:	○ Rustig	○ Druk	○ Zeer druk	○ Gevaarlijk	○ Weet ik niet
4	Om mijn bestemming te bereiken moet ik:	○ Links af	○ Rechts af	○ De weg vervolgen	○ Uitvoegen	○ Weet ik niet

Experiment 1: SART questions and questions related to the sounds.

Beoordeel de onderstaande 3 vragen ten aanzien van de situatie die u zojuist heeft meegemaakt. Doe dit ten aanzien van de gehele situatie die u heeft mee gemaakt, dus zowel wat u heeft gezien als wat u heeft gehoord. Geeft telkens aan in welke mate de stelling geldt door het betreffende rondje aan te vinken.

		zeer weinig	weinig	redelijk weinig	redelijk	redelijk veel	veel	zeer veel
1	Hoe veel aandacht vraagt de situatie?	○	○	○	○	○	○	○
2	Hoe veel aandacht kon u opbrengen voor de situatie?	○	○	○	○	○	○	○
3	Hoe veel heeft u begrepen van de situatie?	○	○	○	○	○	○	○

Beoordeel het geluid dat u tijdens de verkeerssituatie heeft gehoord op de onderstaande 3 stellingen. Geeft telkens aan in welke mate de stelling geldt door het betreffende hokje aan te vinken.

		zeer slecht	slecht	redelijk slecht	redelijk	redelijk goed	goed	zeer goed
1	De hoorbaarheid van de signalen is:	○	○	○	○	○	○	○
2	Elk signaal is apart te herkennen:	○	○	○	○	○	○	○
3	Het comfort van de geluiden in de cabine is:	○	○	○	○	○	○	○

Experiment 2: Auditory signal judgment questionaire

Beoordeel signaal 1 en 2 op onderstaande stellingen. Geef telkens aan in welke mate ze verschillen op betreffende stelling. Indien u de signalen niet vindt verschillen kiest u de middelste optie.

		Signaal 1			Geen verschil			Signaal 2
1	Welk signaal vindt u duidelijker?	○	○	○	○	○	○	○
2	Welk signaal *klinkt* luider?	○	○	○	○	○	○	○
3	Welk signaal klinkt urgenter?	○	○	○	○	○	○	○
4	Welk signaal klinkt meer ergerlijk?	○	○	○	○	○	○	○
5	Welk signaal heeft uw voorkeur?	○	○	○	○	○	○	○

Questions evaluating the research method and regarding attitude towards the principles used

De volgende vier vragen gaan over de verkeerssituaties die u heeft gezien.

		zeer slecht	slecht	redelijk slecht	geen van beide	redelijk goed	goed	zeer goed
1	Hoe goed kon u zich inleven in de verkeerssituatie?	○	○	○	○	○	○	○
2	Hoe realistisch vond u de geluiden?	○	○	○	○	○	○	○
3	Vond u de geluidssignalen goed te herkennen?	○	○	○	○	○	○	○
4	Was de richting van het signaal te onderscheiden? {LDWA/CW}	○	○	○	○	○	○	○

In de verkeerssituaties die u zojuist heeft mee gemaakt werden soms minder belangrijke geluidssignalen afgebroken voor belangrijke signalen. Ook werd soms gebruik gemaakt van radio mute: het verlagen van de luidheid van de radio op het moment dat er een ander geluidssignaal klinkt. De volgende vragen gaan over deze zaken.

		zeer onprettig	onprettig	redelijk onprettig	geen van beide	redelijk prettig	prettig	zeer prettig
5	Het afbreken van minder belangrijke signalen is:	○	○	○	○	○	○	○
6	Het gebruik van radio mute bij waarshuwingssignalen is:	○	○	○	○	○	○	○
7	Het gebruik van radio mute bij navigatie systeem een bericht is:	○	○	○	○	○	○	○

De laatste vraag gaat over het aanpassen van de luidheid van geluidssignalen aan de luidheid van het achtergrond geluid zodat het onder alle condities goed hoorbaar is.

		zeer onprettig	onprettig	redelijk onprettig	geen van beide	redelijk prettig	prettig	zeer prettig
8	Aanpassen van de luidheid aan achtergrond geluid is:	○	○	○	○	○	○	○

Druk op "Verder" om uw antwoorden te bevestigen [Verder]

Appendix C

Recommendations.

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1 Introduction

1.1 Scope

This document provides recommendations for in-truck cabin auditory displays. It applies to all devices installed as OE using sound as a means to provide information or entertainment. Non OEM are beyond this document's scope, however, where possible the presence of non OEM auditory displays are taken into consideration as design influencing factors. These non OEM devices include:
- Radio;
- Navigation systems;
- Telematic systems
- Citizen band radio ;
- Nomadic devices like GSM phones, PDAs.
- Toll Collect

1.2 Field of application

Recommendations are given for the design of all devices currently present in a truck cabin with an auditory display. These devices include:
- DIP;
- DTS;
- Integrated GSM.

Devices that will possibly be installed in the future, like:
- integrated radio;
- active cruise control;
- collision warning systems (OD, SCW, FCW);
- lane departure warning;
- parking help;
- driver alertness monitoring system (European Commission, 2005);
- inter vehicle communications (European Commission, 2005);
- freezing road warning.

This summarization is by no means complete and is dependent on future development and research activities. The sound management system should have provisions for these and other possible additions.

2 General

These recommendations are applicable to all on-board sounds that are implemented to provide information. If references are ambiguous, ISO recommendations are preferred. General (ISO based) recommendations are provided in every chapter, if necessary complemented with application-specific recommendations.

2.1 Definitions

Auditory threshold: the acoustic intensity of a signal which is detected in 50% of all cases within a defined acoustic environment. The auditory threshold is a function of the frequency composition of the signal as well as the background acoustic environment (ISO 16352).

Audibility: The percentage with which an auditory signal is perceived within a defined acoustical environment. For in-vehicle signals, audibility should be as high as possible (usually 95%). Audibility is equivalent to the detection rate of the signal (ISO 16352).

A-weighting: Intensity level taking human hearing capabilities as a function of frequency into account.
dB: Intensity level in Decibel.
DIP: Digital Instrument Panel
DTS: Digital Telematic System
FCW: Forward Collision Warning
OD: Object Detection
OEM: Original Equipment Manufacturer
SCW: Side Collision Warning
SNR: Signal to Noise ratio

2.2 Sources

The sources for these guidelines come from guideline and directive documents by ISO, SAE and the Federal Highway administration, as well as scientific papers. Important literature, for designing and evaluating sounds and sound management:

Edworthy, J., Adams, A. (1996). *Warning design: A research perspective.* London: Taylor & Francis,

Endsley, M. R., Boltė, B., Jones, D. G. (2003). *Designing for situation awareness: an approach to user-centred design.* New York: Taylor & Francis.

ISO (2004). *ISO 15006: Road vehicles – Ergonomic aspects of transport information and control systems – Specifications and compliance procedures for in-vehicle auditory presentation.* International Institute for Standardisation.

Jong, A. J. de (2005). *Afstudeerverslag: Mens-machine interactie in vrachtwagens en de vormgeving van waarschuwingssignalen voor Driver Assistance Systemen.* DAF Trucks n.v. & Technische Universiteit Eindhoven.

Otto, N., Amman, S., Eato, C., Lake, S. (2001). Guidelines for jury evaluation of automotive sounds. *Sound and Vibration*, 1–14.

3 Functional requirements

3.1 General

Auditory presentation is recommended (ISO, 2005)
- because it is omni-directional (independent of head orientation and position);
- because it can not be involuntary shut off;
- since it is a supplement to overloaded vision;
- it can draw attention to visual indicators;
- when vision is limited or impossible.

Precautions with regard to implementation of auditory presentation
- audibility;
- masking;
- learnability;
- confusion;
- user preference.

Every signal should be intended to release certain behaviour by the driver; the designer should formulate this intended behaviour in a clear description. Three types of auditory signals can be used
- earcons, e.g. the "red" warning,
- speech output, e.g., navigation messages,
- auditory icons, e.g. direction indicator relay sound.

People can easily distinguish 4 tones and learn to distinguish 6 to 8 tones, thus the number of earcons should be limited. By using auditory icons or speech messages, the package of auditory signals can be extended substantially because these signals can be understood easily if designed correctly. With regard to warning signals, a system of general warning levels should be implemented (red – amber – green) for providing information on vehicle status.

3.2 Signals

Following specifications are provided to meet usability, comfort and safety criteria of auditory warning signals.

Signal spectrum

The recommended frequency ranges are stated in table 16 for different signal modalities. Pure tones should be avoided because of the risk of masking audibility of the signal cannot be guaranteed. A broad band sound or a mix of narrow band sounds with distinct separated centre frequencies should be used. To take hearing problems (of older people) into consideration, discriminating frequencies should be below 2000Hz.

Table 16, recommended frequency spectra (ISO, 2004).

Signal Type	Minimum (Hz)	Maximum (Hz)
Tonal	400	4000
Speech	400	8000
Auditory icon	400	4000

Signal levels

The detection rate of an auditory signal should be as high as possible, usually 95%. The usable intensity range to reach the detection criterion is 50 dB to 90dB. The SNR should be 5dB to 15dB depending on the function of the auditory signal (ISO 2004). Applicable intensity levels and SNRs for specific urgency levels are stated in table 17.

Table 17, recommended signal levels (ISO 2005).

Auditory areas	Intensity (dB)	SNR (dB)	Type of information
Limit	<50	<5	Reassurance message
Comfort	50 to 70	5 to 10	Speech and announcement message
Emergency	70 to 90	10 to 15	Urgent warnings (immediate collision warning)
Health impairment area	>90	>15	Not recommended

To avoid unwanted responses (caused by startle effect), auditory signals should have a gradual signal level onset. Gradual signal level onset should be dependent on message importance (see table 18) but an increase higher than 1dB/ms is not recommended.

Table 18, recommended gradual signal level onset (ISO, 2004).

urgency	Signal level onset (dB/ms)
High	1
Medium	0.5 to 0.75
Low	0.33

Reliability

Signal reliability should be as high as possible. Systems that have a higher rate of false alarms should have an incremental warning signal design (Bellotti, 2002) thus starting the signal earlier at an increasing intensity instead of introducing the signal at the last moment on full intensity. This results in a lower false alarm rate perceived by the user. Another option is to lower perceived urgency for signals that have a high false alarm rate.

Tones versus speech

The choice between earcons and speech depends on the desired urgency (see table 19) of the message and on the type of information a message should convey (see table 20).

Table 19, basis of choice between tonal or speech messages (ISO, 2004).

Category	Tonal signal (or auditory icon)	Speech
Short-term	Suitable	Not recommended
Medium-term	Suitable	Suitable
Long-term	Suitable as announcement of a visual display or verbal message	Recommended (verbal message)

Table 20, choice between earcons or speech.

Use Tonal signal	Use speech output
When the message is extremely simple	When flexibility of communication is necessary
To specify a moment	When the source of the message has to be identified
When the signal designates a point in time that has no absolute value	
When immediate activity is necessary	When the message deals with a time related, but not immediate activity
When speech messages are overburdening the listener	
When noise conditions are unfavourable for receiving speech messages	
When speech will mask other speech or annoy other listeners	When rapid two-way exchanges of information are necessary
If the user is familiar with the tones	If the user is not familiar with the tones
	When stressful situations are possible which can cause tone codes to be forgotten

3.2.1 Earcons or tonal signals

Earcons should be used "for attracting attention and providing information" (ISO, 2004).

Comprehensibility

For earcons it is necessary for the user to learn the association between signal and the message it conveys. Regular exposure may be needed to clarify and reinforce their meaning (ISO, 2004). Another option is a provision for the user to play the signals for learning.

Temporal classification of signals

Earcons should be designed with respect to the priority level of the event they are intended for. The signal parameters should be adapted in such a way that user perceived priority corresponds to the event priority level. In general a signal should have the following properties with regard to temporal classification:

- Short-term message: Sweeping sounds, bursts of sounds, alternating tone pitch, fast rhythm of dissonance.
- Medium-term message: Patterns of segments with constant pitch, the shortest at least 0,3s.
- Long-term message: Two-times chimes, high-low recurrent followed by a verbal message or visual display.

More specific effects of signal parameter manipulation on perceived priority can be found in table 21 to 23.

Table 21, effect of pulse characteristics on perceived priority (Edworthy & Adams, 1996).

Parameter	Direction of Effect
Fundamental frequency	High > low
Harmonic series	Random / 10% irregular > 50% irregular > regular
Delayed harmonics	No delayed harmonics > delayed harmonics
Amplitude envelope	Regular / slow onset > slow offset
Key: > More urgent than / Equally urgent	

Table 22, effect of burst characteristics on perceived priority (Edworthy & Adams, 1996).

Parameter	Direction of Effect
Speed	Fast > moderate > slow
Number of repeating units	4 > 2 > 1
Rhythm	Regular > syncopated
Speed change	Speeding up > regular / slowing
Pitch contour	Random > down / up
Pitch range	Large > small > moderate
Musical structure	Atonal > unresolved > resolved

Key: > More urgent than

Table 23, exponential rates for alterations of some sound properties (Hellier, 1999).

Warning Parameter	Exponent
Pitch	0.38
Speed	1.35
Repetition	0.50
Inharmonicity	0.12
Length	0.49

Example: if pitch is doubled (100% increase), the sounds perceived urgency will rise 38%.

Directionality
An auditory signal should use directionality to improve problem comprehensibility. The signal should direct to the causing event location, or to more detailed information about the event.

The use of harmonic frequencies around 1000Hz should be avoided to provide good signal directionality detection.

Confusion
Should always be prevented, to achieve this, signal properties have to be clearly distinct between all signals. The most important property to prevent confusion is the temporal pattern (Edworthy, 1996). Further, the fundamental frequency should be different for each signal. To prevent confusion, earcons should not sound like other familiar earcons (Example: computer or telephone sounds). Specific attention should go to signals originating from:
- emergency vehicles
- Toll collect

Speech messages should have be clearly audible and have an unambiguous meaning.

Startle effect
The main function of a warning sound is getting attention of the user, but a startle effect (inadvertent or delayed reaction due to initial startle response) should be avoided. The signal should not be too loud or have a too short onset time (see 3.2 for onset times).

Prevention of signal masking
Signals should not have the risk of being masked by the background noise: signals should have four or more components in the appropriate level range (see 3.2). Having all the energy concentrated at only one harmonic leads to a greater risk of masking (Patterson 1990).

Signals should not mask each other: prioritization can deal with this: the most important signal will be presented first, or a lower priority signal should be cut off when a higher priority signal comes on.

Other important signals coming from outside the vehicle (for instance railroad crossing sounds or emergency vehicle alarms) should be audible in all cases. In-cabin sounds should have clearly distinct signal patterns distinguishing them from outside signals.

Maximum number of signals
Use up to 4 signals if absolute discrimination is required (not taking vocal signals and auditory icons into account). If combined with speech or designed as an auditory icon, more signals can be used.

Ergonomic warning sound
The prototype ergonomic warning sound as designed by Patterson (figure 13) can be used as a basis for the signal design. The warning is build up of several bursts having different intensities; a burst consists of a pattern of pulses.

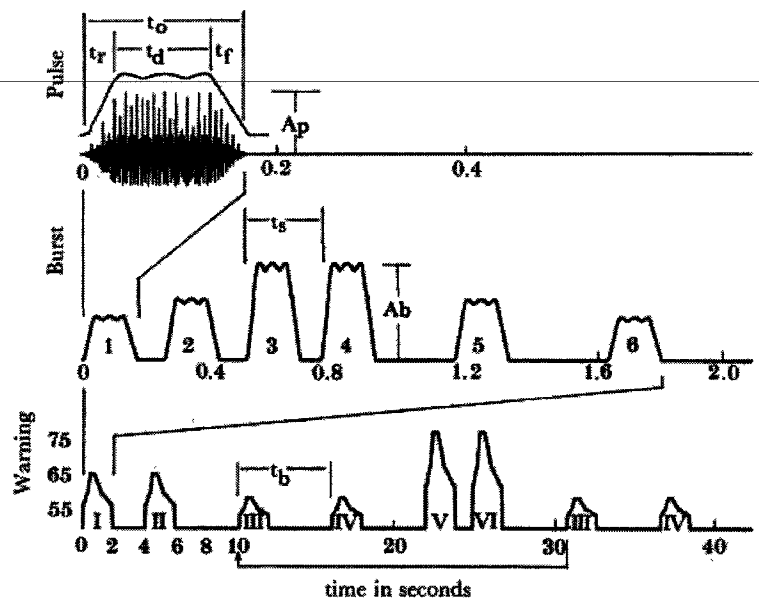

Figure 13, example of temporal characteristics warning sound.

The signal is build up of a basic pulse which has a waveform unique to a particular warning. This pulse is used to construct a burst, a temporal pattern of pulses (with variations in pulse amplitude, the first pulses somewhat lower to avoid startle) giving the warning a specific rhythm. The temporal pattern can be used to manipulate the perceived urgency of the warning. The complete warning can have a pattern like shown in the bottom row in figure 13, a temporal pattern of bursts varying in relative amplitude. First the signal should be brought under attention of the user using a moderate amplitude level. Assuming the user has heard it, and is working on a solution, the next bursts can have a lower amplitude level to avoid irritation. If nothing has been done after some time, the bursts come one at their highest level to indicate that the problem still persists.

3.2.2 Speech messages

Speech messages "should be used if the driver has sufficient time to listen to the full message before it is necessary to choose a course of action" (ISO, 2004). Speech messages should be used in (ISO 2005)

- time-sharing tasks where rather low information processing is required;
- tasks involving verbal information, such as the names of any devices;
- tasks involving information that is already in an acoustical form;
- tasks involving the presentation of information which has a high priority, e.g. pointing out a drop in oil pressure;
- tasks involving information to be memorized for several seconds.

Spoken messages can be entirely synthesized or they can be constructed from (digitized) real human speech. Characteristics should be such that the messages can easily be differentiated from other speech sources (e.g. passenger talking or speech coming from the radio). Synthesized speech has the advantage that it has the capability of presenting complex messages like email or SMS messages. Intelligibility of digitized real speech is better (although synthesized speech is improving on this field).

Design considerations (ISO, 2004):

- use 5 information units or less ("close to Eindhoven" is one significant unit of information);
- present sequence information units in order of potential relevance;
- provide key words, prosodic cues and highlighting;
- provide redundant visual displays;
- provide means for the driver to request message repetition.

In case of longer messages, important parts of a speech message should be presented at the beginning or the end of the message; these parts are remembered best.

Landmarks are important navigation tools for humans; they can be used in navigation or traffic messages.

Length of traffic congestion and the direction of it are more difficult to remember compared to the place (if environment is familiar to user) and cause.

3.2.3 Auditory icons

For auditory icons, the same general design principles are applicable as for earcons. Auditory icons are more easily classified, identified and categorized, thus the number of understood and remembered auditory icons significantly exceeds the number of earcons that can be remembered and understood. However, auditory icons should not be used for urgent warnings as they lead to more false reactions compared to traditional tonal warnings.

Auditory icons should always be tested with regard to recognition of the event or sound they resemble. It should be noted that there can also be differences between countries with respect to this (Example: rumble strips in the Netherlands sound different from those in Germany): thus signals should be tested for recognition in different countries.

3.3 Integration (sound management)

If possible, auditory devices should be integrated into the sound management system to limit the risk of conflicts. (Offer a second car kit.) Redundant visual displays should always be provided for auditory warnings. If applicable, the different modalities should be presented congruent, e.g. the direction indicator sound should be presented analogue to the flashing of the indicator symbol. Incongruency with visual display can lead to slower, less accurate user response.

3.3.1 Adjustability

There is a large variation in background noise in road vehicles; besides, users have different hearing capabilities and preferences. To meet these differences, the auditory system should be flexible. The system should have (ISO, 2004):

- Signal adjustability: ± 10dB (A-weighted); the user should be provided with means to adjust a signal ± 10dB (A-weighted) from the predefined setting.
- Provision to switch the system off (except for safety critical messages).
- Automatically adjustable auditory level to the frequency spectrum of background noise; if problems are found concerning signals being too loud or not audible due to changes in background noise, than automatic volume control should be implemented to adjust their auditory level to the frequency of the background noise thus keeping SNR constant.
- Frequency specific amplification should be provided which allows the user to adapt the signal to his or her hearing capabilities, especially for speech messages.

Automatic adjustability is difficult from a technical point of view. Adapting the frequency spectrum of signals used can provide a (partial) solution to this. If background noise has frequency ranges with high variability, the signal should have frequency components located outside this problematic frequency range.

3.3.2 Prioritization

The designer should develop a clear rank-order regarding priority of all events that result in an auditory signal being displayed. A first step to achieve this, is to order auditory sources according to driving task relatedness, as shown in table 24. Tasks are:

- *primary driving relevant task* (consists of forward visual tracking and road hazard monitoring for safe driving)
- *secondary driving relevant tasks* (like reading road signs, or determining direction, obtaining information needed to drive and to find the correct route)
- *driving irrelevant tasks* (all other possible non driving related tasks a driver could carry out while driving, like listening to music, or a telephone conversation)

Table 24. A first step for deciding on prioritization: order signals with regard to task type. The numbers in the "Task type" column indicate importance; 1 indicates the most important sounds, than follows 2 and 3 indicates the least important sounds.

Device		Type	Task type	Intended Behaviour
DIP	Warning Red	Earcon	1 Primary driving	stop vehicle in a safe way
	Attention Yellow	Earcon	2 Secondary driving	read message on DIP
	Direction indicator lights	Speech	2 Secondary driving	feedback/notice
	Alarm Clock	Earcon	3 Driving irrelevant	notice
DTS	Navigation	Speech	2 Secondary driving	follow route advice
	e-mail	Earcon	3 Driving irrelevant	notice/read message
	Traffic message	Speech	2 Secondary driving	adapt route
LDWA (Lane Departure Warning)		Earcon /Icon	1 Primary driving	steering correction
ACC (Active Cruise Control)		Earcon	1 Primary driving	note slowing front vehicle
CW (front, side, rear)		Earcon	1 Primary driving	collision avoidance
OD (dead corner)		Earcon	1 Primary driving	collision avoidance
Parking Help		Earcon	1 Primary driving	collision avoidance
GSM signal		Earcon /Icon	3 Driving irrelevant	Pick up phone/read message
GSM communication		Speech	3 Driving irrelevant	Vocal communication
Radio		Speech/var	3 Driving irrelevant	non/changing route
CB (Citizen Band Radio)		Speech	3 Driving irrelevant	Vocal communication
Toll Collect (Maut collecting system)		Earcon	3 Driving irrelevant	notice

The sound management system should prevent simultaneous delivery of signals and should provide sufficient temporal separation between signals: at least 1 second (Wiese, 2004). Safety critical messages should never be presented exclusively by auditory means.

Options to deal with priority according to ISO15006 (ISO, 2004):
- sequence of the presentation is determined priority;
- only the higher priority message is presented;
- the ongoing lower priority message is stopped and delayed/deleted;
- one message will be presented through the auditory mode and the other one trough the visual mode.

With "auditory presentations" are meant: All auditory signals in the form of tones, icons or speech, radio broadcasts, phone conversations.

The system should ensure that the most urgent signal is always audible. Thus, lower priority auditory presentations:
- should be stopped when a higher priority issue becomes active;
- should not be presented during a high priority issue;
- should be delayed if the system measures a certain increase in the possibility for a high priority message needing to be presented. Example: Collision warning sounds when vehicle headway is >2 seconds, and delays lower priority messages when vehicle headway is >3 seconds

Higher priority auditory presentations:
- Should be presented preferably at least 1 second after termination of a lower priority signal
- Should mute the radio thus providing a larger intensity range for auditory presentations and increasing detection by user probability.

Exceptions:
- Conversations via phone or citizen band radio should never be interrupted.

Provision of a possibility to learn the signals should be implemented; e.g. a menu option for the user to play the signals at will, or by making the signals audible at system start-up. This is especially important for important warning signals.

4 Compliance procedures

4.1 Measurement

Measurement conditions and equipment requirements found below are integrally taken from ISO 15006 (2004).

Measured quantities
All readings of the sound level meter are to be taken with the dynamic characteristic "fast" and the values to be measured at the microphone are the A-weighted sound pressure level expressed in decibel or LAeq energetic level expressed in decibels, A-weighted.

Measuring equipment
The sound level meter is of the precision class according to IEC 60651.
For the measurement of noise spectra, the filters meet the requirements of IEC 60225.

Installation
The acoustical measurements are conducted either in a laboratory environment (i.e. a quiet environment) or, preferably, with sound-generating devices installed in the vehicle in the real location.
The microphone(s) used for the sound measurement will be located close to the driver's ears. The requirements of ISO 5128 shall be followed regarding the outside acoustical environment (see Clauses 6 and 7).

4.1.1 Background noise

For determination of the masked threshold, background noise should be measured using octave band analysis or 1/3 octave band analysis on a frequency range of at least 200Hz to 10000Hz.

4.1.2 Audibility

Audibility of signals can be predicted by the use of octave band analysis or 1/3 octave band analysis (see ISO7731). The sound level shall exceed the masked threshold by at least 10dB in one octave band or more in the frequency range 300 to 3000Hz (ISO, 2004) for earcons. This should be tested under an extreme background noise condition.

4.2 Testing

Literature elaborating on sound evaluation and tests:

Otto, N., Amman, S., Eato, C., Lake, S. (2001). Guidelines for jury evaluation of automotive sounds. *Sound and Vibration,* 1–14.

ISO (2004). *ISO 15006: Road vehicles – Ergonomic aspects of transport information and control systems – Specifications and compliance procedures for in-vehicle auditory presentation.* International Institute for Standardisation.

Jong, A. J. de (2005). *Afstudeerverslag: Mens-machine interactie in vrachtwagens en de vormgeving van waarschuwingssignalen voor Driver Assistance Systemen.* DAF Trucks n.v. & Technische Universiteit Eindhoven, Eindhoven.

Keser (2007) *Masters Thesis: Sound management in a truck cabin.* DAF Trucks n.v. & Eindhoven University of Technology, Eindhoven.

4.2.1 System review

First of all, the current system has to be reviewed (if applicable) regarding the users attitude and problems found under usage circumstances. Attitude towards the current situation, warning sound usage and other interfering sounds (background noise, conversation, radio) should be measured. If possible, reactions to the existing warning sounds should be investigated. A questionnaire format study is applicable for this.

4.2.2 Discriminability

All earcons should be tested for perceptual discriminability, method (ISO, 2004):

- Identify or record all earcons of a vehicle.
- Adjust the signals for equal loudness (subjectively or by measuring sound amplitudes (see 4.1).
- ~~Select 10 participants with normal hearing abilities.~~
- In a training session, present the earcons to the test participants and let them select a nominator for each signal. Training should have 10 repetitions or reach an error free test cycle.
- In a test session, 90% correct answers are required for each signal to pass the discriminability condition.

4.2.3 Perceived Priority

The complete set of warning signals should be tested with regard to priority: the signal that has the highest priority should also have the highest perceived priority. Perceived priority can be tested the following way:

- Direct comparisons, Judge 2 sounds on urgency (Edworthy, 1996)
- Judge a single signal: highly urgent....not urgent at all
- Judgement by drawing a line, the longer the higher its estimated urgency. (Edworthy 1993)
- Judgement by ordering signals (Edworthy 1993)

4.2.4 Sound management

The learning of important warning sounds should be tested.
For testing different sound interfaces, see chapter "experiment" in the "Sound Management in a truck cabin" report.

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ISO (2005). *ISO/TR 16352: Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems.* International Institute for Standardisation.

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Patterson, R. D., Mayfield, T.F. (1990). Auditory warning sounds in the work environment [and Discussion]. *Philosophical Transactions of the Royal Society of London, Vol. 327 (1241),* 485 – 492.

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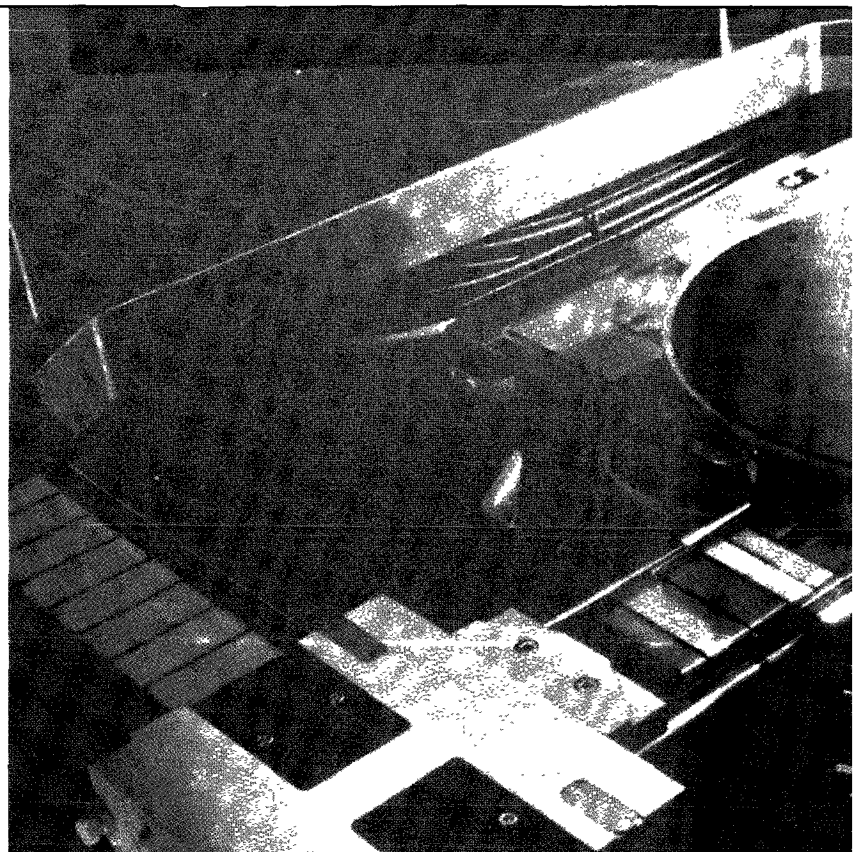

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