MAKING AUDITORY WARNING SIGNALS INFORMATIVE: EXAMINING THE ACCEPTANCE OF AUDITORY ICONS AS WARNING SIGNALS IN TRUCKS

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Summary: Auditory icons have the potential to enhance a driver's situation awareness, to reduce his or her visual load, and to improve his or her response time in an emergency situation. However, the level of acceptance of this type of auditory signal as a warning signal is not well understood. The present study was carried out to investigate truck drivers' initial acceptances of auditory icons as warnings. The drivers selected warning signals for a number of dangerous driving situations. A method that was based on subjective ratings was also used to assess the drivers' acceptances of the sounds and to gain a better understanding of the factors that influence the drivers' selections. The results showed that the level of acceptance can be very high, but it varied significantly among the auditory icons that were encountered in five driving situations. Perceived "usefulness" and "satisfaction" may be used to determine whether the drivers prefer an auditory icon in specific situations. However, the subjective ratings related to the satisfaction should be complemented with a deeper qualitative investigation when examining the acceptance of auditory icons as warnings.

INTRODUCTION

Auditory warnings and alerts are now commonly implemented in advanced driver assistance systems (ADASs). Signals that include sound have unique advantages over visual options in emergency situations. Hearing is omnidirectional, while visual warnings must be seen [1]. However, whereas simple auditory signals are used to attract attention, the detailed information is most often presented visually, either outside in the traffic environment or inside the vehicle through visual displays.

The concept of auditory icons was first introduced by Gaver (1986). He defined them as "everyday sounds mapped to computer events by analogy with everyday sound-producing events". Auditory icons differ from other non-verbal sounds in user interfaces in that they sound like what they represent, which tends to make auditory icons meaningful in the context in which they are presented. In contrast, conventional warnings are arbitrarily mapped to their alarming function. Previous research has shown that auditory icons are easy to learn and interpret compared to other non-verbal signals (Leung, Smith, Parker and Martin, 1997; Dingler, Lindsay and Walker, 2008; Fagerlönn and Alm, 2009). Auditory icons may also lead to faster driver responses in urgent situations compared to simple tones and speech messages (Graham, 1999). Belz, Robinson and Casali (1999) reported that truck drivers respond significantly more quickly to auditory icons compared to repetitive tone pulses in a collision situation. Additionally, meaningful sounds can enhance safety by amplifying the driver's awareness of his or her surroundings (Chen, Qvint and Jarlengrip, 2007) without adding to his or her visual load. One potential issue with the use of auditory icons as warnings is that the level of acceptance of these

sounds may be low. Belz et al. (1999) reported that about half of the participating truck drivers were sceptical about the use of auditory icons, indicating that they did not considered these signals to be serious warnings in commercial vehicles. Thus far, little research has focused on drivers' acceptances of auditory icons as warning signals for commercial vehicles. The acceptance of warning signals may depend largely on factors that are not directly related to the sound, such as the rate of false warnings (Block, Nuutinen and Ballast, 1999). However, investigating the initial acceptance of the auditory signal is important. Drivers who do not find a sound appropriate may turn it off or even reject the system. However, if the level of acceptance is very high, that can also be valuable information for developers intending to implement auditory warning signals in future ADASs. Furthermore, if designers plan to use auditory icons in warning systems, we must know more about the perceived qualities of these systems that impact the acceptance of these sounds as warning signals. One aim of the present investigation was to study commercial drivers' initial acceptances of auditory icons for conveying information in potentially dangerous driving events. A second aim was to examine the underlying factors that affect the acceptance of auditory icons as warning signals in trucks.

METHODS

In the present study, I used two complementary methods. In the first method, drivers selected warning signals for five driving situations using a visual interface. In the second method, I used a procedure described by Van der Laan, Heino and de Waard (1996) to access the drivers' acceptances of the auditory icons in each of the five driving situations.

Twenty-two truck drivers (2 females and 20 males) between the ages of 23 and 63 years (mean age: 38.4 years; SD: 12.3 years) participated. They reported an annual driving distance between 10.000 and 250.000 km (mean: 94.410 km; SD: 53.640 km). All of the drivers reported normal hearing.

The trials were conducted inside of a Scania R truck cabin. The interface PART (Liljedahl and Fagerlönn, 2010) was back-projected 2.90 metres in front of the cabin. The experimenter could control this interface from inside the cabin. The interface showed videos of driving situations, and the participants could control the playback of these videos via the experimenter. They were also able to choose the exact point in the video at which a warning should be triggered. Another part of the interface was used to select the auditory warnings for the driving situations. The drivers could choose from 162 variants of arbitrary warning signals. These signals were arbitrary in the sense that they were not designed to convey any specific meaning to the drivers about any of the driving situations. They were all pulses of sounds that were played in a distinct pattern. Their lengths ranged from 0.5 to 1.2 s. The participants could also select one of three warning modes for each driving situation. If the participant selected the "no warning sound" mode, no warning sound was played in that situation. If they selected the "arbitrary" mode, then the arbitrary sound was triggered at the indicated point in the video. If the "arbitrary + auditory icon" mode was selected, the brief arbitrary sound was first triggered, and then an auditory icon was played to give information about the situation. The auditory signals were presented using a 5.1 speaker system (Anthony Gallo Acoustics Inc, CA, USA). I used background noise that was recorded inside a Scania truck travelling at a speed of 60 km/h during the trials. The background noise was calibrated to approximately 61 dBA at the driver's position.

The driving situations were staged and recorded from inside a Scania R truck near Stockholm, Sweden. In the "lane departure" situation, the driver was travelling on a straight three-lane motorway. After some time, the truck started to drift slowly to the left into the next lane. The auditory icon representing this situation was a low-frequency rumble noise, similar to tires on road grooves. In the "collision" situation, the truck was driving on a straight road. A passenger car, initially hidden behind terrain and vegetation, approached an intersection from a connecting road. The car suddenly became visible and began to pull out in front of the truck. This situation was represented by a car horn. In the "slippery road" situation, the driver was heading into a curve on a slippery road. This situation was represented by the sound of ice scraping. In the "cyclist" situation, the driver was heading toward an intersection with the intention to turn right. A cyclist caught up with the truck on the right side and stopped in the blind spot. The driver then started to turn right. The sound of a bicycle bell was used to represent this situation. In the "traffic queue" situation, the truck was driving on a motorway entrance. There was a traffic queue on the motorway, and the driver had to brake to avoid a collision. This situation was represented by a number of horns playing simultaneously.

The drivers were told that the objective of the study was to investigate commercial drivers' attitudes towards the use of auditory signals for a range of in-vehicle systems. They were introduced to the visual interface that displayed the driving situations. The drivers were instructed to select warning sounds for the driving situations. They were told to select options that they would prefer to have appear in a truck while driving. While making their selections, the drivers were allowed to suggest any alternative solutions. For example, if they preferred a visual display instead of a warning sound, they were allowed to suggest the use of a visual sign. After the subjects felt satisfied with their selections, they listened to the auditory icons again. The participants were then required to rate each representative sound according to the procedure, as recommended by Van der Laan et al. (1996). The participants made judgements about their experiences of the sounds using nine, five-point rating scale items. The items were related to two scales; one scale denoted the perceived usefulness, and one scale designated the perceived satisfaction. The scales that were related to usefulness assessed the following values: worthless/assisting, useless/useful, superfluous/effective, sleep-inducing/raising alertness and bad/good. The scales related to satisfaction assessed the following values: unpleasant/pleasant, undesirable/desirable, irritating/likeable and annoying/nice. The nine rating items were presented in a mixed order. The drivers' selections of the warning modes during sound selection and the usefulness and satisfaction scores that were associated with the auditory icons in the five driving situations defined the dependent measures in the evaluation.

RESULTS

Figure 1 shows the drivers' selections of the sounds for the different driving situations. Considerable differences were observed in the drivers' selections of the warning modes for the five driving situations. In the "lane departure" and "cyclist" situations, 18 and 17, respectively, of the 22 participants selected an auditory icon. In the other driving situations, only 5-7 participants selected an auditory icon.

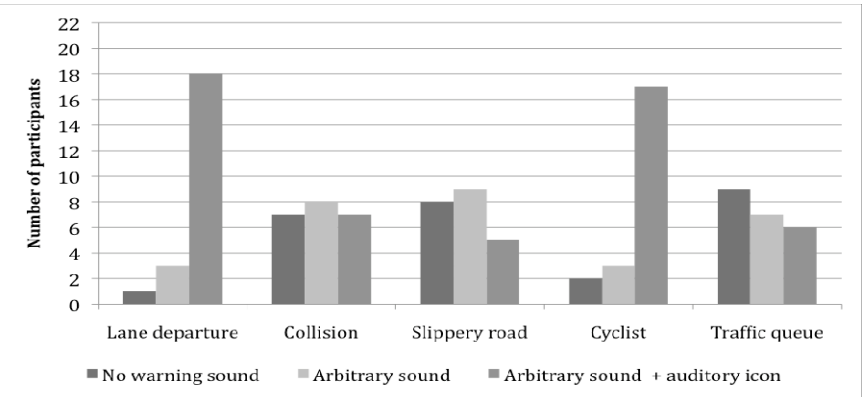

Figure 1. The subjects' selections of the warning modes for the five driving situations

Subjective ratings

Table 1 shows the mean subjective scores, standard deviations, reliability measures and correlations for the subjective ratings.

Table 1. Results of the subjective ratings; Correlations are for the usefulness and satisfaction scores, Pearson's correlation coefficient (two-sided test)

	Lane departure	Collision	Slippery road	Cyclist	Traffic queue
Usefulness (SD)	1.23 (0.70)	-0.18 (1.28)	-0.60 (1.20)	0.53 (1.39)	-0.30 (1.11)
Worthless – assisting	1.27 (0.70)	-0.09 (1.54)	-0.64 (1.36)	0.50 (1.60)	-0.27 (1.35)
Useless – useful	1.27 (0.55)	0.00 (1.45)	-0.36 (1.40)	0.59 (1.56)	-0.18 (1.40)
Superfluous – effective	1.18 (1.05)	-0.64 (1.40)	-0.68 (1.36)	0.41 (1.50)	-0.59 (1.18)
Sleep-inducing – raising alertness	1.23 (0.97)	0.18 (1.40)	-0.50 (1.34)	0.73 (1.42)	-0.23 (1.07)
Bad – good	1.23 (0.81)	-0.36 (1.40)	-0.82 (1.37)	0.41 (1.47)	-0.23 (1.19)
Satisfaction (SD)	-0.05 (0.67)	-0.34 (0.95)	-0.76 (-1.05)	0.06 (1.23)	-0.43 (0.93)
Unpleasant – pleasant	-0.36 (0.85)	-0.05 (1.13)	-0.59 (1.26)	0.14 (1.13)	-0.27 (1.03)
Undesirable – desirable	1.00 (0.87)	-0.55 (1.37)	-0.91 (1.31)	0.18 (1.53)	-0.50 (1.30)
Irritating – likeable	-0.73 (0.98)	-0.41 (1.05)	-0.91 (1.02)	-0.09 (1.27)	-0.55 (1.10)
Annoying – nice	-0.09 (1.27)	-0.36 (1.22)	-0.64 (1.40)	0.05(1.29)	-0.41 (1.05)
Cronbach's α useful. / satisf.	0.89/0.59	0.82/0.81	0.93/0.86	0.95/0.95	0.94/0.84
Correlation useful. – satisf.	0.26	0.75*	0.86*	0.93*	0.94*

* $p<0.01$; standard deviations in parentheses

The scores ranged between -2 and +2. The reliability tests for the items related to the usefulness and satisfaction resulted in Cronbach's alpha values (above 0.65, as recommended by Van der Laan et al. 1996) for all situations, except for the satisfaction component in the "lane departure" situation. I found that the auditory icons for the "lane departure" and "cyclist" situations received the highest usefulness and satisfaction scores. However, none of the sounds received particularly high satisfaction scores. I used a one-way ANOVA to investigate the differences in the subjective ratings between the auditory icons for the five driving situations. Significant differences were found for the usefulness scores $F(4,84)=14.1$, $p<0.01$ and the satisfaction scores

$F(4,84)=3.53$, $p<0.01$. The post-hoc analyses using Tukey's honestly significant difference (HSD) test revealed that the usefulness score for the "lane departure" situation was significantly higher than the scores for the sounds in the other situations ($p<0.01$), except for the auditory icon in the "cyclist" situation. Tukey's HSD test also revealed that the usefulness score for the "cyclist" situation was significantly higher than the scores for the "slippery road" ($p<0.01$) and "traffic queue" ($p<0.05$) situations. The satisfaction scores for the "lane departure" and "cyclist" situations were significantly higher than that for the "slippery road" situation ($p<0.05$). Interestingly, I found strong positive correlations between the usefulness and satisfaction scores for the sounds in four of the five driving situations (Pearson, $r = 0.75$-0.94, $p<0.01$, two-sided), indicating that the drivers who found the sound useful also found it satisfying (and vice versa).

Comparing drivers' selections and subjective scores

The two most selected auditory icons received significantly higher usefulness scores compared to the sounds for the other situations. I used a univariate logistic regression analysis to investigate the associations between the drivers' selections and the usefulness and satisfaction scores. The results of the analysis are shown in Table 2. I found that both components were significant predictors of the drivers' selections in two of the five driving situations. The odds ratios (ORs) higher than 1.0 indicated that the drivers that gave a sound a high score were more likely to select the sound in the selection task. The results indicate that the usefulness and satisfaction scores are appropriate predictors to determine whether a driver prefers an auditory icon as a warning signal. I found no significant association between the usefulness and satisfaction scores and the drivers' selections for the "lane departure" situation (only four drivers did not select the auditory icon for this situation).

Table 2. Results from the logistic regression analysis

	Usefulness			Satisfaction		
	OR	95% CI	p-value	OR	95% CI	p-value
Lane Departure	0.84	0.157-4.48	0.830	1.05	0.20-5.44	0.95
Collision	3.96	1.20-13.03	0.024*	2.82	0.75-10.58	0.124
Slippery Road	2.25	0.90-5.66	0.082	3.74	1.03-13.59	0.045*
Cyclist	4.07	1.33-12.49	0.014*	5.47	1.37-21.63	0.016*
Traffic Queue	9.3	1.10-79.05	0.002**	23.58	1.19-466.41	0.038*

* $p<0.05$; ** $p<0.01$; OR=odds ratio; CI=confidence interval

Demographic data and subjective ratings

Investigating the relationships between the demographic data (age and annual driving distance) and the subjective responses was not the primary aim of the present study. However, I found a positive significant correlation between the usefulness scores for the "lane departure" situation and the drivers' annual driving distance (Spearman, $r = 0.54$, $p<0.01$, two-sided). The auditory icon for this situation received the highest usefulness score, and it was interesting that the drivers who drive the most tended to rate the sound particularly useful.

DISCUSSION

The results of the sound selection task indicate that the level of acceptance was high for the auditory icons in two of the situations but that there was a considerable variation between the auditory icons for the different driving situations. Many of the drivers selected auditory icons in the "lane departure" and "cyclist" situations. In addition, an analysis of the subjective ratings revealed significant differences in the subjective scores for the auditory icons, especially in terms of the usefulness. The results suggest that system developers should seriously consider the use of auditory icons when implementing warning systems. Not only could auditory icons become very effective warning signals, but drivers may also show a high level of initial acceptance of these sounds.

I also found that the usefulness and satisfaction scores can be used to determine whether an auditory icon is preferred in a driving situation. The most frequently selected auditory icons received significantly higher usefulness scores compared to the auditory icons in the other situations. This result indicates that perceived usefulness may be an especially important quality for auditory icons when presented as warning signals in trucks. None of the auditory icons received particularly high satisfaction scores. However, the positive correlations that were observed between the usefulness and satisfaction scores for four of the five driving situations indicate that the two components are closely related. Furthermore, the logistic regression analysis revealed that the satisfaction score was a significant predictor of the drivers' selections for three of the driving situations. Therefore, a low level of perceived satisfaction is most likely a negative quality of auditory icons as warning signals in commercial vehicles.

Three of the four rating items that comprise the satisfaction component (pleasant/unpleasant, irritating/likeable and annoying/nice) are related to perceived annoyance. Previous research has found that a high level of annoyance is an inappropriate quality for low urgency warnings but not necessarily for high urgency warnings (Marshall, Lee and Austria, 2007). Additionally, McKeown (2005) investigated the annoyance of auditory icons for in-vehicle use and found that drivers consistently rated auditory icons that were mapped to more urgent situations as being more annoying. With these previous results in mind, it was a bit surprising that higher satisfaction scores were obtained for the dangerous "cyclist" situation. In contrast, I found that the auditory icon for the very dangerous "lane departure" situation was considered to be irritating and unpleasant rather than likeable and pleasant. Furthermore, no significant correlations were found between the usefulness and satisfaction scores for this particular auditory icon. Some of the participants may have rated this sound as irritating and unpleasant because the sound indicated a very dangerous situation. In summary, it is a challenge to interpret the satisfaction scores of the auditory warnings. It may not be sufficient to ask the participants whether they find a particular sound annoying, irritating or unpleasant, etc. To make more valid judgements about the level of acceptance, we must also ask the subjects why they rate the sound in such a way, and whether their rating indicates a good or bad quality of the particular signal.

The popular auditory icon that was presented in the "lane departure" situation was considered useful, especially by drivers that reported a high annual driving distance. I recommend that future research should investigate how the acceptance of auditory icons can depend on the individual characteristics of drivers. A better understanding of the individual differences would

have implications for the system designers that intend to offer personal settings for in-vehicle warning signals. Furthermore, it is likely that the drivers' attitudes will change over time, for example, if the drivers found a signal helpful. Future studies should investigate the acceptance of auditory icons after their prolonged use.

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