Auditory Messages for Speed Advice in Advanced Driver Assistance Systems

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ABSTRACT
Simple tones in in-car systems are mostly used for status indication or warning and alerting purposes. We argue that simple tones can also be used for the purpose of advising drivers through an Advanced Driver Assistance System (ADAS). Our ADAS application is called Cooperative Speed Assistance (CSA), where drivers receive advice to slow down or speed up to coordinate their speed with the speed of other vehicles in the traffic. Two concepts of auditory messages are presented: Looping messages are played as long as the advice applies, while Toggle messages mark the beginning and the end of an advice. For each concept, two prototypes of simple-tone signals were designed based on existing guidelines about sound characteristics affecting urgency and evaluation by users. The temporal characteristics of the signals indicated how much or how fast drivers should adapt their speed. The concepts were evaluated by having users drive in a driving simulator. Objective measurements indicated that there was no difference in effectiveness between the two concepts. Subjective evaluation indicated that users preferred the Toggle concept.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces –Auditory (non-speech) feedback, User-centered design

General Terms
Design, Experimentation, Human Factors

Keywords
Automotive user interfaces, ADAS, auditory display, sound design

1. INTRODUCTION
Auditory signals have been used for In-Vehicle Information Systems (IVIS) or Advanced Driver Assistance Systems (ADAS) for quite a few years. An example of the use of auditory signals is provided by navigation systems, where speech messages are used to inform drivers about which direction to take. According to [3], there are several types of auditory signals: simple tones, earcons, auditory icons, speech messages. While speech messages are mostly appropriate to display qualitative and quantitative information, simple tones are best for status indication and alerting (attentional) signals.

Our research focuses on a nomadic Advanced Driver Assistance System (ADAS) which assists drivers in adjusting their speed cooperatively with the speed of surrounding traffic in order to bring about a smooth traffic flow and prevent shockwaves. The choice for a nomadic system was based on the assumption that it favors a faster market penetration, so that more vehicles in the traffic can be equipped with the speed regulation system and beneficial effects on traffic flow occur at a faster rate. In cooperative driving there are no fixed speed limits, but the recommended speed always changes according to the traffic condition. In such situations drivers need simple and clear speed advice such as Slow Down and Speed Up. In this paper we investigate opportunities for using non-speech auditory messages to provide speed advice to drivers.

The literature reports evaluations of several speed management systems such as the Intelligent Speed Adaptation system (ISA) [1]. In one experiment, haptic and auditory feedbacks for a speed management system were compared and the result indicated that the majority of drivers preferred to keep the auditory beep system even though it showed lower satisfaction ratings than the haptic pedal system. This result shows the acceptability of using auditory feedback in speed management systems.

Moreover, in case of nomadic systems, the use of the haptic modality to inform drivers is limited. This leaves us with easily available modalities for aftermarket devices: visual and auditory. We designed an aftermarket device called Cooperative Speed Assistance (CSA) involving visual and auditory feedback. As a first proposal, we would like to investigate appropriate auditory feedback to be used in the CSA system.

A recommendation by Deatherage (1972) as cited by [18] is to use the auditory modality if: the message is simple, short, and transient; the message deals with events in time; the message calls for immediate action; the visual system is overburdened; etc. This recommendation fits properly to the driving context where the visual system may be overburdened. In this respect, the auditory modality has an advantage over the visual modality, as indicated by the result of [17], where a visual interface distracted users from performing the primary task of driving, thus reducing its efficiency.

Several additional advantages may be listed for the auditory modality compared to the visual modality in driving. In the first place, the auditory modality allows for a faster reaction of drivers toward in-vehicle messages compared to a Head Down Display [13], which is the only visual display solution in currently available aftermarket IVIS/ADAS. Another advantage of the auditory channel in the context of ADAS is that it is omnidirectional [16], as auditory information can be picked up comfortably while driving, where users are not supposed to change their head or body orientation. Furthermore, sensory memory for the auditory channel lasts longer than for the visual channel, so that auditory information can be processed with some delay. Finally, it is impossible for people to "close the ears", so that the auditory channel is good for alerting functions.

In a recent user test with a speed advice system [20], speech messages were used to inform drivers about recommended speech, but the use of speech appeared annoying. This adds up to the anecdotic evidence that the use of speech messages in the car is fraught with difficulties, as it is easily considered annoying by drivers. For that reason, we will explore the use of non-speech audio signals.

The messages in the CSA system, although advisory, need also be alerting to drivers. Other than simple tones, using auditory icons and earcons can be considered, but we argue that they are not appropriate for the context of CSA. Auditory icons should resemble certain sounds (iconic), which are difficult to derive from the Slow Down and Speed Up events in cars. The use of engine sounds is considered a drawback from existing technology of insulating passengers from engine sounds. Earcons are synthesized musical timbres, which create a too large design space. Narrowing down the parameters to pitch only can reduce earcons to simple tones. Moreover, the use of auditory icons and earcons for alerting messages is still to be re-investigated [2][9]. The use of simple tones would be appropriate for giving the basic messages of Slow Down and Speed Up. The actual target speed (non-timing related) may then be communicated through the visual display in the system.

This paper explains the process of sound design. The concepts for in-car auditory signals are proposed and the design of the simple tones by construction is explained in Section 2. Section 3 describes a test aiming to evaluate the concepts of displaying the auditory signals while driving. A conclusion and discussion section follows in Section 4.

2. SOUND DESIGN

2.1 Guidelines

One of the properties that can be delivered by auditory signals is urgency. In the CSA system, the messages Slow Down and Speed Up should bear the message indicating how much to slow down or speed up, as the difference between the current and the advised speed can be larger or smaller.

Studies on manipulating sound characteristics to manipulate urgency levels have provided several guidelines, such as: higher pitch means higher urgency, shorter inter-pulse interval means higher urgency, faster tempo means higher urgency, etc. [5][11]. When the urgency is higher, people also react faster to the auditory signals [6][19]. This way, urgency can be appropriately related to how much slower/faster people react to an auditory signal. Therefore, we designed the auditory signals for CSA by incorporating urgency as the main parameter to be conveyed by the Slow Down and Speed Up messages. We also need to develop one or more prototypes to be evaluated and tested by users using some methods from [7].

2.2 Concept

Four designers (two of them involved in sound design) were invited to discuss the ideas for Slow Down and Speed Up messages for CSA. Three concepts were suggested: Continuous signals, Looping signals, and Toggle signals. Continuous signals give continuous information whether the driver needs to slow down or speed up or whether the speed is OK; that is, the signals are always heard inside the vehicle. This concept was dropped as it would be too annoying. Looping signals and Toggle signals were chosen for the design to be composed of simple tones.

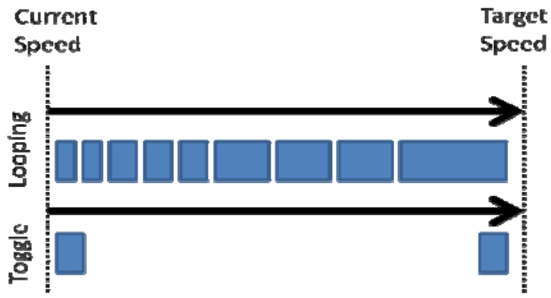

Figure 1. Looping signals and Toggle signals

In the Looping concept, when an advice needs to be given, an auditory signal is displayed. This signal expresses a certain urgency level that tells the driver about how much to slow down / speed up. The signal is repeated (looping) with decreasing urgency as the driver executes the advised task towards the target speed.

In the Toggle concept, when an advice needs to be given, an auditory signal is displayed. This signal expresses an urgency level that tells the driver about how much to slow down / speed up. The driver needs to slow down / speed up until an OK signal is displayed, informing her/him that s/he has reached the target speed. A potential disadvantage of this concept compared to the looping concept is that it is displayed only in the beginning, so that the instruction needs to be retained in working memory, causing potential mental load.

2.3 Tones Design

For the purpose of sound prototyping, four tones were constructed consisting of sine waves of 60 degree phase using GIPOS[8] with fundamental frequencies of 400Hz, 500Hz, 600Hz, and 800Hz. We refer to the terms pulse, burst, and signal as proposed by Patterson (1982) cited by [18], where a pulse consists of the basic tones from fundamental frequencies, a burst consists of repetition of pulses combined with inter-pulse (silence) periods, and a signal consists of a series of bursts combined with inter-burst (silence) periods.

For each fundamental frequency, three pulses were created: 100ms, 200ms, and 400ms in length. To create a perceived softness on each pulse, a fade in effect of 20ms (onset time) and a fade out effect of 100ms (offset time) were applied on each of them. Therefore, there were 12 basic pulses varied by 4 frequencies and 3 lengths. From the 12 pulses, four sets of burst prototypes were designed. Each prototype consists of 6 bursts, varied by 3 different levels of urgency and two types of message (Slow Down and Speed Up).

Main design considerations were as follows. Pitch was used to code the direction of speed change, with rising pitch signaling an advice to speed up and falling pitch signaling an advice to slow down. Urgency was coded by the length of the pulses and the inter-pulse intervals.

Several small-scale tests were conducted with a small number of designers to evaluate various aspects such as learnability, confusability and identification of the Slow Down / Speed Up and urgency attributes. In addition, qualitative feedback was obtained by asking the evaluators about the relationships between sound characteristics and information attributes.

The qualitative comments confirmed our expectation that the pitch changes from high to low would be interpreted as Slow Down messages, and the pitch changes from low to high would be interpreted as Speed Up messages.

The urgency levels were less well understood. The source of confusion for the urgency levels was mostly related to the length of the pulses and inter-pulse intervals. To most evaluators, shorter pulse length meant higher urgency. However, they considered longer pulses to be more prominent or insistent or more salient than shorter ones, thus indicating that a more persistent signal implied higher urgency. It can be concluded that careful distinction should be made between the effects of the length of the pulse and of the inter-pulse interval on perceived urgency level. If inter-pulse intervals are increased, then pulse length should be made uniform among signals.

2.4 Tones Redesign

The four sets were redesigned into two sets. In the first place, to overcome the problem of confusions between urgency levels, the pulse length was set at a fixed value of 100ms. Only the duration of the inter-pulse interval was manipulated (decreasing length = more urgent). Secondly, it has been noted by [7] that it is “fairly important to impose some sort of experimental control over the stimuli so that some are not more noticeable than others on the basis of non-acoustic cues”. Therefore, the duration of signals should be held constant, to overcome the problem of short urgent messages being easily missed by drivers. Because of the equal duration, shorter bursts are repeated more often than longer bursts. We decided to set the duration at 1500ms after studying the choice of durations in previous studies [12][14][15][21].

The description for the two sets of redesigned signals is illustrated by figures. Prototype 1 consists of 6 bursts of 2 pulses each, and an example of a medium urgency Slow Down signal is shown in Figure 2. Prototype 2 consists of 6 bursts of 3 pulses each, and an example of a medium urgency Slow Down signal is shown in Figure 3.

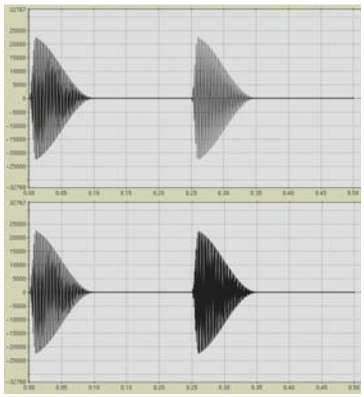

Figure 2. Prototype 1 (2 pulses) for medium urgency – Top: Slow Down (600Hz[100ms], 150ms, 400Hz[100ms], 150ms); Bottom: Speed Up (600Hz[100ms], 150ms, 800Hz[100ms], 150ms)

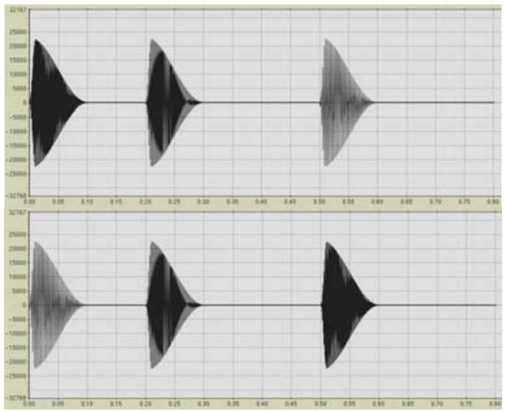

Figure 3. Prototype 2 (3 pulses) for medium urgency – Top: Slow Down (800Hz[100ms], 100ms, 600Hz[100ms], 200ms, 400Hz[100ms], 200ms); Bottom: Speed Up (400Hz[100ms], 100ms, 600Hz[100ms], 200ms, 800Hz[100ms], 200ms)

For the purpose of the driving test, the OK signal for the Toggle concept was designed using a fundamental frequency of 550Hz of 100ms length with two additional lower-amplitude pulses (delay effect) of 100ms each, making in total 300ms duration of the signal.

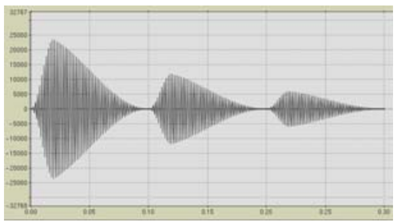

Figure 4. The 300ms length OK signals

Both sets were re-evaluated with four designers. At least 3 out of 4 evaluators distinguished the pairs in the sets correctly. Both the

Slow Down / Speed Up messages and the urgency levels were recognized correctly. One evaluator expressed being confused about the Slow Down and Speed Up messages. The increasing pitch is supposed to signal an advice to Speed Up, but it might also be interpreted as signaling that the car is too fast and the driver needs to slow down (a Slow Down advice). The results also indicated that keeping the pulse length constant and varying the length of the inter-pulse interval has a strong effect on perceived urgency levels, which is in line with the recommendation of [4].

Additional comments from evaluators indicate that the use of repeated bursts (thus equal duration) ensured equal audibility of all message types and urgency levels (2 evaluators). One evaluator was unable to distinguish medium and low urgency signals but could still recognize the varied length of inter-pulse intervals and used it as a basis for distinguishing urgency levels. In the following section we describe an experiment in which both sets were evaluated in a realistic context with a driving simulator.

3. DRIVING EXPERIMENT

3.1 Preparation

Sound-displaying software connected to a medium-fidelity fixed-based driving simulator [10] was developed for the purpose of the test. The software generates Slow Down and Speed Up messages by displaying pulses with the appropriate fundamental frequencies and inserting different inter-pulse and inter-burst silence periods between the pulses. The inter-burst intervals are always twice as long as the inter-pulse intervals. The inter-pulse intervals are generated real time based on how much the current speed is faster/slower than the target speed given by the traffic in the simulator. The minimum inter-pulse interval is 50ms and the maximum inter-pulse interval is 1000ms.

3.2 Methods

Twelve drivers (8 male, 4 female, age 20-29) were invited for a driving experiment. Each participant spent up to 5 minutes driving to get used to the driving simulator. They were then requested to drive four additional rounds using the two prototypes in Looping and Toggle concepts. This took them driving four 5-minute blocks where in each block they experienced one of the following conditions: Prototype 1 in the Looping concept, Prototype 1 in the Toggle concept, Prototype 2 in the Looping concept, and Prototype 2 in the Toggle concept, consecutively. The order of conditions was balanced across participants.

After each 5-minute time block, they were asked to rate their mental effort while driving using the system compared to normal driving, among other things because the Looping and Toggle concept may induce different degrees of mental load. The rating was measured by the Rating Scale for Mental Effort (RSME) scale [22].

After each RSME rating, participants were also asked to rate the recognizability of the urgency, the annoyance, and the appropriateness of each condition (combination of concept and prototype). The scale is from 0 to 10, so the urgency recognition ranges from no urgency detected to always detected urgency, the annoyance ranges from not annoying to always annoying, and appropriateness ranges from not appropriate at all to very appropriate.

3.3 Qualitative Results

Nine out of 12 users chose the Toggle concept over the Looping concept. For the sample size (N=12), Binomial test doesn't show significance (p=.15). The Toggle concept was considered less stressful and the OK signal was liked by users. A user said that he needs the OK signals for confirmation, because if he only hears beeps (like in Looping concept) then he doesn't know whether he has to expect more coming signals or not. Similarly another user wants to know whether he already reached the advised speed or not. A user commented that by using OK signals it is easier for matching with the advised speed, without having to look at the speedometer.

Among users who chose the Looping concept, a user explained that it makes the signal keep coming so when it's not there he knows that it's not advising speed anymore. Another user commented that he feels like he's more free to control the signal's occurrence. The OK signals were considered too frequent and cannot tell the exact target speed, so it's annoying if they're too much. One user choosing the Toggle concept mentioned that the Looping concept is more accurate but annoying.

Ten out of 12 users chose Prototype 1 (2 pulses) over Prototype 2 (3 pulses) prototype. One user was undecided due to a learning effect (they sounded similar). For the sample size (N=12), Binomial test doesn't show significance (p=.07). The 2-pulse prototype was considered simpler, not confusing, more easily understood. Users who chose this prototype considered that the 3-pulse prototype is more obtrusive, annoying, and harder to understand.

Users who chose Prototype 2 commented that the 3-pulse prototype was more obvious, more salient, not ignorable. However, generally participants liked both the 2-pulse and 3-pulse signals because they thought that the pitch difference clearly indicated advices for Slow Down and Speed Up. Only two people indicated that the pitch should be lower. Interestingly, one user mentioned unavailability of target speed as limiting their knowledge on how fast/slow to reach the target speed.

3.4 Quantitative Results

There was no significant difference between RSME ratings by users after each system, between concepts and between prototypes. It shows that each concept and prototype was rated as "some effort" (the means for each concept and prototype ranging from 32.75 to 37.83). No correlation was found between annoyance and RSME ratings, and the same applies for urgency recognizability and appropriateness.

There was also no significant difference between urgency recognizability, annoyance, and appropriateness between concepts and between prototypes. The means (on a scale from 0 to 10) for annoyance was 4.25, for appropriateness was 5.75, and for urgency recognizability was 6.29.

For further analysis of the driving behavior, we compared the effectiveness of the Looping and the Toggle concepts grouped by Prototypes. The average speed response of the drivers was calculated separately for the Slow Down and Speed Up advices. The speed response was defined as a five seconds interval after a signal was given, measuring at a 2Hz frequency (each 0.5 seconds). The speed responses using Prototype 1 for the Looping and Toggle concepts are shown in Figure 5 and Figure 6. The Speed responses using Prototype 2 for the Looping and Toggle concepts are shown in Figure 7 and Figure 8.

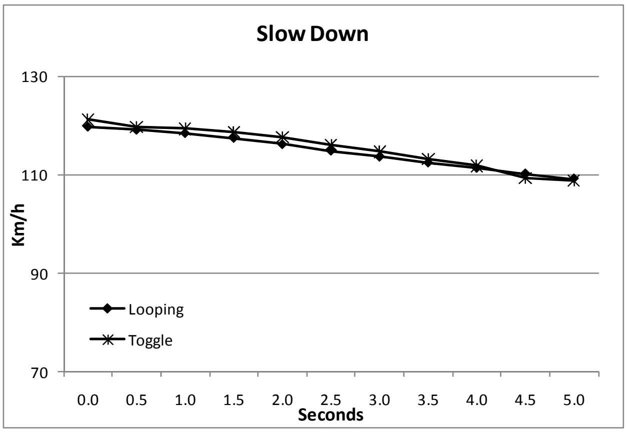

Figure 5. Driver's speed changes in response to Slow Down messages (Prototype 1)

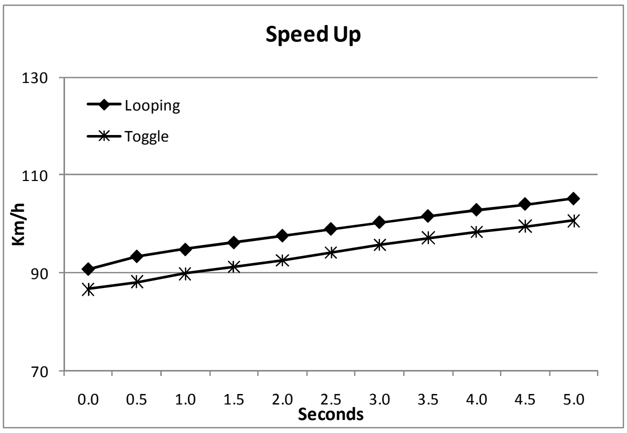

Figure 6. Driver's speed changes in response to Speed Up messages (Prototype 1)

The driver's responses to Slow Down and Speed Up messages of Prototype 1 are approximately identical between concepts. The lower start-up speed in the Speed Up graph for the Toggle concept is coincidental, but the progression of the speed on average shows a similar curve as for the Looping concept.

Using Prototype 2, the driver's responses to Slow Down and Speed Up messages also show similar trends. However, the Looping concept caused slightly faster responses as represented by a steeper gradient of the curve compared to that of Toggle concept. This effect is visible both for Slow Down and Speed Up messages as shown in Figure 7 and Figure 8 respectively.

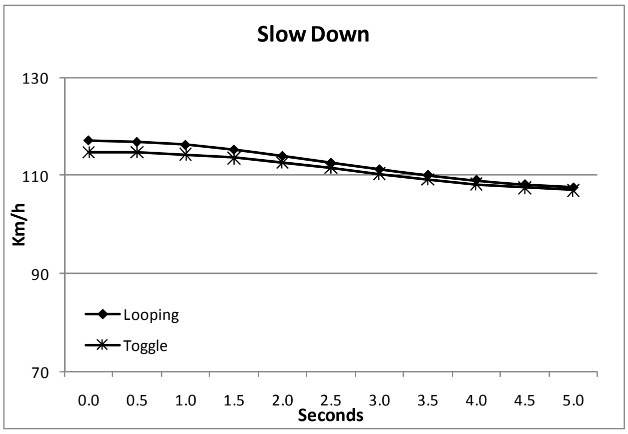

Figure 7. Driver's speed changes in response to Slow Down messages (Prototype 2)

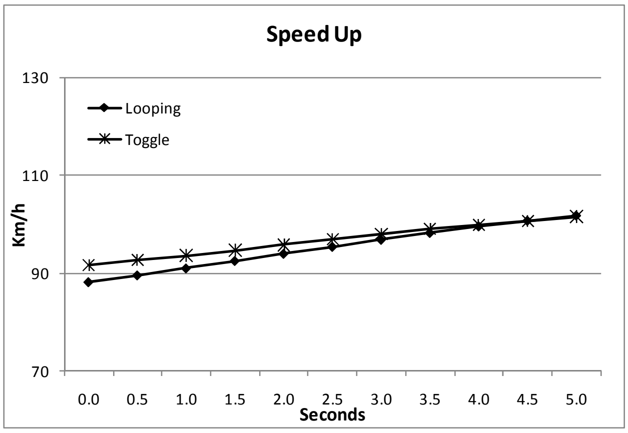

Figure 8. Driver's speed changes in response to Speed Up messages (Prototype 2)

4. CONCLUSION AND DISCUSSION

We proposed a design for advisory auditory signals to be used by a speed assistance system, by using simple tones. The speed response data indicated that Slow Down signals made people slow down and Speed Up signals made people speed up. The analysis of the speed response data showed that both concepts are equally effective in guiding the driver's behavior as indicated by the 2-pulse prototype, and the Looping concept is more effective than the Toggle concept as indicated by the 3-pulse prototype.

Comments of the participants showed that the manipulation of the fundamental frequency of the auditory signal for coding Slow Down and Speed Up and the manipulation of the inter-pulse intervals for coding urgency were successfully applied.

The driving test results showed moderately low annoyance and moderately high urgency recognizability based on subjective judgment by users. The subjective mental effort was also considered low ("some effort").

The Looping and Toggle concepts presented to users could be distinguished clearly by advantages and disadvantages. Most users preferred the Toggle concept and their preference was supported by convincing arguments (regarding annoyance and confirmation).

In terms of prototype choice, we can argue that the smaller number of pulses in the 2-pulse prototype indicated less annoyance as explained by users who preferred the 2-pulse prototype. In terms of concept choice, it is difficult to make a trade-off between user's subjective and objective data.

Regardless of user's preferences, the 3-pulse signals can distinguish the effectiveness of the Looping concept from the Toggle concept in guiding drivers to meet speed requirements. Users' comments on the salience of the 3-pulse signals support this behavior. Although more users chose the Toggle concept, we propose that for urgent messages such as Slow Down (people tend to drive too fast) the Looping concept can be used, and for less urgent messages such as Speed Up the Toggle concept can be used.

One point to take into consideration in judging the validity of the conclusions relates to the way the participants reacted to the different concepts. In total within 5 minutes of driving with the Toggle concept the system displayed fewer advices (means 13.83) compared to driving with the Looping concept (44.67) ($t=13.07$, $df=46$, $p=.00$). This may be due to the following. In our driving test, the CSA system would not give a new advice if the most recent advice was not yet executed by the driver. With the Toggle concept, which consisted of a single auditory signal, drivers may not have noticed the advice, thus continuing to drive on the same speed. Even though the system displayed the signal again after 5 seconds if the driver did not react, the asymmetry in the number of signals remained. Furthermore, this asymmetry may also explain why the Toggle concept was considered less annoying than the Looping concept.

Overall, the effectiveness of the different concepts in cooperative speed assistance for improving traffic flow is discussable compared to automated systems. The advantage of advisory speed assistance system lies in its ability of engaging the driver's attention (preventing mental underload), and the disadvantage lies in the delays carried into traffic flow from the perspective of traffic management. Another disadvantage is the lack of comfort when the advisory signals get too annoying, but this can be adjusted by filtering advices for better comfort. Given this consideration, we have shown that non-speech auditory signals can be designed that it informs the driver about what to do in a timely and not-annoying manner.

In future research we will continue with driving simulator tests combining visual and auditory feedbacks in the CSA prototype. The effectiveness and appreciation of the Looping concept and the Toggle concept will be investigated again by combining auditory and visual information in a multimodal display. We will also investigate whether acceleration cues can be more effective than speed cues for guiding drivers to meet speed requirements. With more detailed data logged for the driver's behavior, we will determine which auditory concept is more appropriate for combination with the visual display.

Finally, since tests with driving simulators have limitations, the effectiveness of the auditory signals for cooperative speed assistance needs to be validated through road and field tests.

5. ACKNOWLEDGMENTS

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