

BENEFITS OF INTUITIVE AUDITORY CUES FOR BLIND SPOT IN SUPPORTING PERSONALIZATION

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ABSTRACT

Supporting drivers with auditory cues has been shown beneficial, but is also known to reach a certain level of annoyance. To fully understand the benefits of intuitive auditory cues as an HMI element, further research is needed.

This paper investigates the benefits of increasing input to aid in the reduction of hazard risks caused by blind spot using intuitive auditory cues. Intuitive auditory support is a naturalistic sound of an object using volume to indicate the distance of the side object (including blind spot area). The experiment involved twenty participants (2 women, 18 men) between 21 and 24 years of age. The experiment was conducted in a 360-degree view simulator with a car body on a turntable with a six-axis control. Using lane change scenarios, participant-perceived benefits of enhanced awareness of hazards, feelings of increased security, and annoyance caused by intuitive auditory support, were compared to a USNCAP target blind spot warning system (with buzzer), and unsupported as baseline systems. For this, subjective measures (i.e., survey analysis), as well as galvanic skin response data to measure participants' physiological responses, were used. The results indicate that intuitive auditory cues support enhanced hazard awareness, increase the participants feeling of security, and are perceived to be less annoying for rare drivers compared to blind spot warning, while for frequent drivers a blind spot warning seems to better support these variables.

Our results indicate that auditory support provides a suitable basis for supporting

those who drive only rarely in lane change maneuvers (supporting maneuverability, providing a feeling of security, and decreasing annoyance levels compared to BSW). Research thus far shows that auditory support could irritate drivers. However, our results do not confirm this. Intuitive auditory support appears less annoying than existing BSW technology. Furthermore, ASIS seems to decrease drivers' stress levels compared with no support.

We suggest that personalization could improve blind spot warning systems, by integrating auditory cues for drivers who drive rarely and keeping BSW technology for the remaining groups.

KEYWORDS

Auditory support; Personalization; Blind Spot Warning;

1. INTRODUCTION

Supporting drivers by means of auditory cues has been shown to provide numerous benefits. Human beings have the innate ability to respond quickly to hazards when exposed to a certain triggering sound. However, inappropriate sound levels may increase annoyance. The sound system design should therefore consider both the annoyance factor and effectiveness in conveying necessary information to the driver. Intuitive sound has been shown to facilitate a more rapid and accurate driver's response with greater user satisfaction [4]. However, whether it is helpful in complex driving tasks was not addressed. Previous research has tested an advisory 3D auditory cue (earcon) for blind spot information showing an effect on improving driver performance and situation awareness [9]. Although participants generally rated the system as useful, they did not find it satisfying. Therefore, it is necessary to further investigate the benefits of using auditory cues considering the HMI elements in supporting real driving contexts.

This paper investigates the benefits of intuitive auditory support for blind spot, targeting the research question:

Do intuitive auditory cues for blind spot increase the perception of improved driving?

We broke down our research question into three detailed questions focusing on enhanced hazard awareness, feelings of security, and annoyance levels:

- Is the use of intuitive auditory cues perceived as increasing awareness of hazards?
- Does the use of intuitive auditory cues support a greater feeling of security?
- Is the use of intuitive auditory cues perceived as annoying?

We investigated these research questions for the scenario of using intuitive auditory cues with naturalistic sounds of side objects (including the blind spot area), using volume change, increasing as the side object comes closer, arguing that for an auditory support to be intuitive, it must use volume to indicate extraneous vehicle movement. Intuitive auditory support is compared to blind spot warning (BSW) systems and no support.

Subjective ratings (e.g., user surveys) were documented to compare results. Furthermore, galvanic skin response (GSR) measures were used to investigate the physical response of participants during lane change activity.

The experiment involved 20 participants (2 women, 18 men) between 21 and 24 years of age. They had normal or corrected-to-normal eyesight, and had their driving licenses from less than one to over 3 years (i.e., one participant less than one year, ten from one to three years, and nine more than three years) and a mix of rare to frequent drivers (i.e., seven rare, seven occasional, six frequent drivers).

Our results indicate that

- ASIS supports an increase in enhanced awareness of hazards for rare drivers (ease of driving), while for frequent drivers it seems to be the case with BSW,
- ASIS increased a feeling of security for rare drivers, while frequent drivers showed a tendency towards an ease in driving using BSW,
- Rare drivers seemed less annoyed using ASIS than BSW, while frequent drivers think the opposite,
- In general, all groups felt ASIS was less annoying than BSW,
- All drivers had decreased GSR levels, which indicates less stress with ASIS.

From these results we conclude that ASIS seems to be generally less annoying for users than BSW while decreasing GSR values, indicating lower stress levels using ASIS compared to no support. Furthermore, when it comes to personalization, ASIS seems highly supportive to rare drivers in lane-changing activities, as our results suggest that this group feels a heightened awareness of hazards, a greater feeling of security, and less annoyance than using BSW support.

While we have not shown significant results for all these measures for the other two groups, it appears that frequent drivers show a tendency to prefer BSW. However, more research is needed to further investigate whether ASIS or BSW would be the system of choice.

2. EXPERIMENTAL DESIGN

2.1. Participants

The experiment involved 20 participants (18 men, 2 women), whose ages ranged from 21 to 24 and had normal or corrected-to-normal eyesight. Prior to the start of the experiment, all participants received an explanation of the contents and the risk of the experiment, their rights, and voluntarily signed a participation agreement. This study was approved by the Ethical Committee of Shibaura Institute of Technology and by the Honda Motor Co., Ltd., respectively.

Participants held a driver license from less than 1 year to over 3 years (i.e., one participant less than one year, ten from one to three years, and nine more than three years). Their driving frequency varied (from driving once yearly to daily).

The literature indicates that driving experience has an impact on driver perception and awareness. For example, experienced drivers are more skilled and have a shorter response time the detection of potential hazards [7, 2]. Gazing behavior studies also indicated a difference in visual search strategies and characteristics depending on driving experience [3]. In addition, the cognitive workload level was significantly different between experienced and inexperienced drivers in traffic conditions of varying complexities [6].

Hence, for the purpose of investigating our hypothesis, we have allotted participants to three groups, based on their driving experience. We define participants that drive as:

Rare (7 participants): Driving once a year to once a month.

Occasional (7 participants): Driving once a month to 4 times a week.

Frequent (6 participants): Driving equal to or more than 5 times a week.

2.2. Simulator Setup

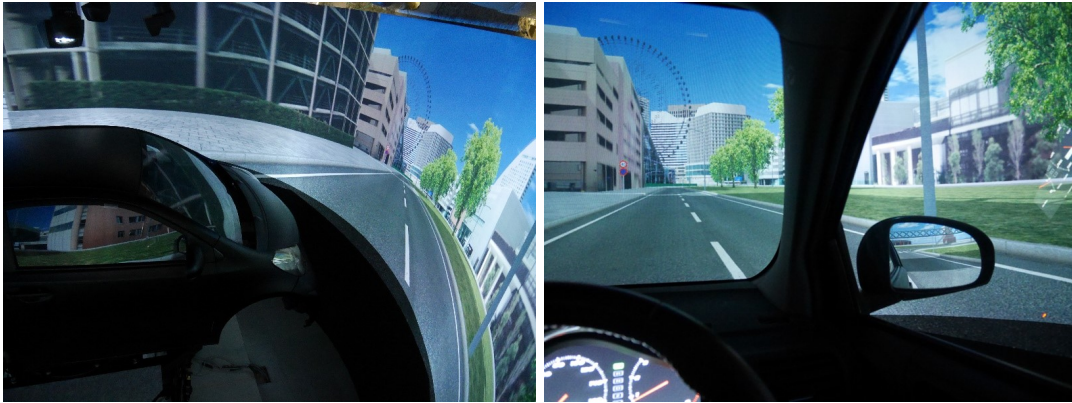


Figure 1. Simulator provides a seamless 360-degree view and a six-axis control turntable

The simulator of Shibaura Institute of Technology was used for this experiment. It contains an actual car body, has seamless 360-degree screen integration and a six-axis control with a turntable to simulate a natural driving experience. Participants drove in a simulator; the scenario was a sudden lane change. Participants drove on a two-lane street in a city zone (no motorway, no pedestrians or cyclists were involved). The side-objects involved in the scenario consisted of two-wheelers (motorcycles) and four-wheelers (passenger vehicles, some buses and trucks): the composed ratio was 2:8, respectively. Participants were instructed to adjust their speed to synchronize with the surrounding vehicles' speed. The speed of all surrounding vehicles was set at 40km/h to avoid unnecessary distraction from watching the speedometer to control speed accurately. Hence, both lanes had vehicles driving at the same speed. They were then instructed to stay in the same lane except when the occasion required a lane change. The lane change was initiated by having the vehicle in front of the ego vehicle decelerating/stopping. Examples of such occasions were vehicles that would decelerate at a bus stop behind a slowing bus, a vehicle turning to park by a shop or restaurant, a vehicle stopping to react to fallen objects, and so on.

Each participant performed 18 driving iterations in the simulator consisting of four lane changes. For the 18 iterations, the test conditions were altered both by support system (ASIS vs. BSW vs. NS) and environmental conditions. The environment was switched between suburban and city with different levels of congestion. In the city the time headway between vehicles in the same lane was 3.2 seconds, and for suburban it was 3.5 seconds. To achieve variation in the tests the operator changed the relative position of the vehicles in the two lanes. While each participant started the first test iteration with NS, other test conditions were randomized. For each of the three systems, six iterations were performed, three iterations for city and three iterations for suburban conditions. After participants completed the three test iterations for one specific system for one specific condition, they received the survey to complete.

Three lane changes did not have a system trigger and was therefore removed, so the analyzed data set consisted of 1337 lane changes.

2.3. Stimuli

Based on the above simulator setup and lane change scenario, three systems are compared, one baseline and two systems that inform the existence of an approaching vehicle in the blind spot area. A blind spot area is defined as the area the driver cannot confirm with mirrors (illustrated in Figure 2).

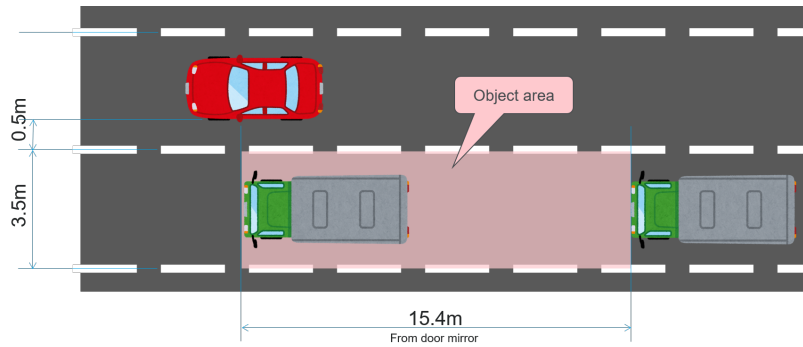


Figure 2. The blind spot area is 15.4m long. The ASIS area for side object identification has been extended to 37m to be able to use increasing volume as a way of creating an intuitive auditory support.

The systems used in this experiment are explained as follows:

ASIS (Intuitive Auditory Surround Information System): This is the main system of evaluation in this study. This information system has been designed for this study and has not yet been introduced to the market. ASIS uses auditory cues based on information from the blind spot area, extending the considered area to 37 m to integrate an intuitive auditory support system by increase their volume. Reflecting moving object signals (distance, velocity etc.) a sound relative to the ego vehicle was used. Natural sounds (i.e., vehicle and motorcycle motor sounds for the two types of objects (2- and 4-wheelers) were transferred to the driver through headphones when an object reached the blind spot. Thus, subjects could expect information of an approaching vehicle, approximate distance and speed by 3D sound control, which is not just on or off but also sounding more intuitive. The volume was changed based on the distance of the object to the ego vehicle (e.g., sound turns louder as the object comes closer to the ego vehicle) linearly reflecting its relative distance/speed. However, the relationship between sound volume and distance or speed could be affected by the subject's own experiences and interpretations.

BSW (Blind Spot Warning): This system is used in the evaluation and represents an existing system, well known to consumers. The driver receives support through a blind spot warning. In this experiment, we used a BSW vehicle algorithm (USNCAP target) and indication method illustrated in Figure 3.

The amber BSW symbol is illuminated when a moving object enters the designated blind spot area and switches off when the object moves out of the area. Even if some objects remain in the blind spot when a driver turns the steering wheel to initiate a lane change, a buzzer is provided and continues while the steering wheel is turned. The buzzer's sound is similar to a normal beep with intervals.

NS (No Support): This is used as a baseline in the experiment and represents current or older vehicles unequipped with systems to inform the driver of surrounding



Figure 3. BSW indication method used (USNCAP target).

situations, but where the driver needs to recognize and judge it through their own eyes and physical mirrors with no technical machinery support.

2.4. Measurements

To understand the benefits of intuitive auditory cues for blind spot to support personalization this experiment included questionnaires to collect participants' views and evaluations. Furthermore, this data was enriched by including physiological measures.

Subjective Measures: Subjective measures were collected four times from each participant throughout the experiment. After each test of a specific support system (i.e., BSW city, BSW suburban, ASIS city, ASIS suburban) was completed, participants were requested to respond to the following questions:

- Did you feel it was easier to drive with the support system?
- Did you feel an increased level of security using the support system?
- Did you find the support system annoying?
- Please add any other opinions about the support system.

For the rating, a five-level Likert scale was used, ranging from 1 (absolutely disagree), 2 (slightly disagree), 3 (neither agree nor disagree), 4 (slightly agree), to 5 (definitely agree).

Physiological Measures: To include physiological reactions from the drivers on each of the system supports used, Galvanic skin response data was collected using an electrodermal activity unit (AP-U030, Miyuki Giken Co.) with electrodes placed on the soles of the feet to measure skin sweat gland (e.g. eccrine gland) activity in microSiemens (μS). Skin glands are responsive primarily to emotional (e.g. stress and arousal) and psychological stimuli. GSR was used as an indicator of stress level during real world driving tasks [5, 8]. Data was then processed using Ledalab (version 3.4.9) to extract the phasic and tonic components of a discrete response triggered by lane change maneuvers. The sum of amplitudes of all significant reconvolved GSR functions within the onset time window were compared by using a two-way ANOVA analysis.

3. RESULTS

3.1. Ease of Driving

Figure 4 depicts the answers from the participants on the first question of easier driving from the questionnaires, representing subjective data. It can be observed that

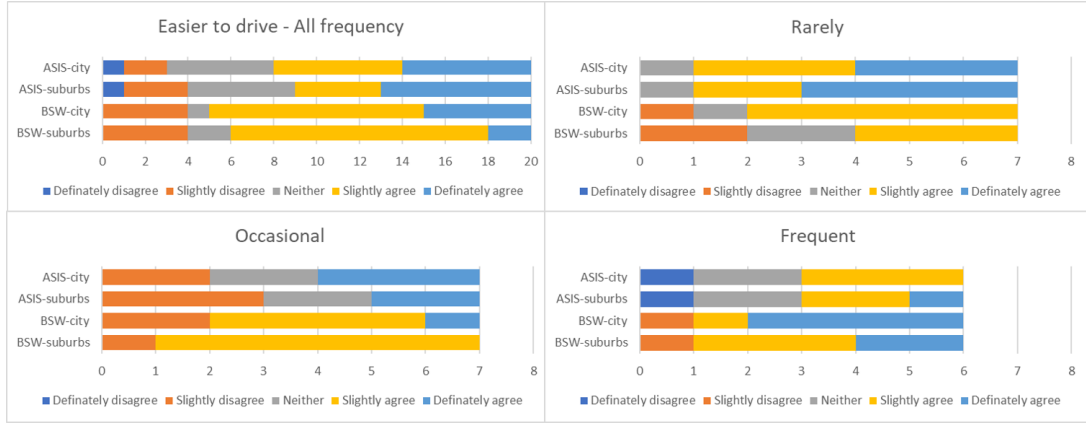


Figure 4. Overview of participant answers for easier to drive.

for both systems, BSW and ASIS, more participants agreed than disagreed that the system made driving easier. When analyzing driving frequency separately, it showed that drivers who rarely drive rank the ASIS system highest, with similar results for both environments, city and suburban roads. However, from the frequent driver group more participants agree (definitely) that BSW enables easier driving. The ratings for occasional drivers are spread between "slightly disagree" and "slightly agree" for BSW and between slightly disagree to definitely agree for ASIS.

Table 1 presents the overall descriptive statistics. The median was used as an indication of the general tendency of participant's feeling on the system. The results suggest that rare drivers felt an increase in ease of driving compared to the BSW group. On the other hand, frequent and occasional drivers felt an increase in ease of driving with BSW. A preliminary test on this data for statistical significance confirmed that for rare drivers ASIS is ranked significantly higher, while for the combined group of frequent and occasional drivers BSW ranked significantly higher than ASIS.

Table 1. Overview of median and standard deviation for ease of driving.

	BSW median	ASIS median	BSW S.D.	ASIS S.D.
Rare	4	4.5	0.842	0.745
Occasional	4	3	0.929	1.336
Frequent	4.5	3.5	1.115	1.215
All	4	4	0.992	1.207

3.2. Feeling of Security

The descriptive statistics for the feeling of security score are depicted in Table 2. The results indicate that for the rare driver group ASIS provided an increase of secure feeling (for details of secure feeling all responses from the participants are depicted in Figure 5). For frequent drivers, we see a tendency towards BSW for an increase of a secure feeling.

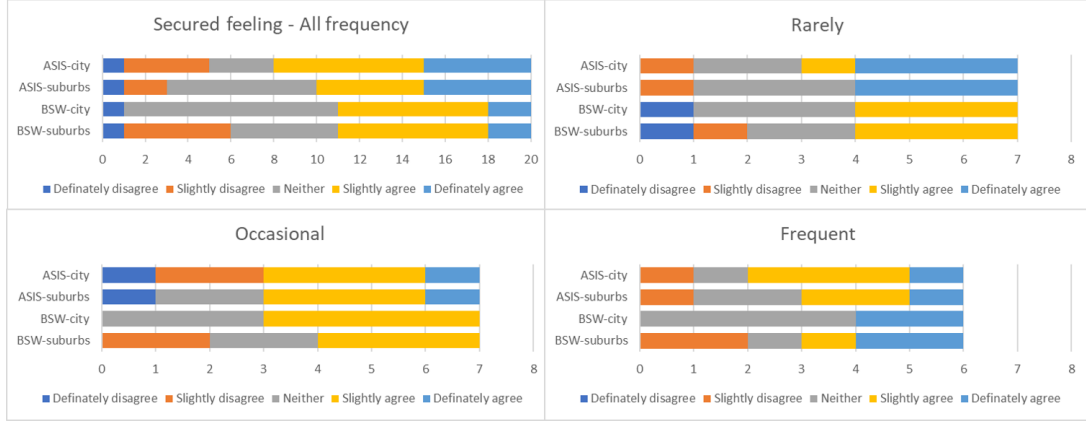


Figure 5. Overview of participant answers for a feeling of security.

Applying preliminary statistical testing, it seems that ASIS can contribute to a significantly increased secure feeling for the rare driving group as well as the combined group of rare and occasional drivers.

Table 2. Overview of median and standard deviation for secure feeling.

	BSW median	ASIS median	BSW S.D.	ASIS S.D.
Rare	3	4	0.726	0.699
Occasional	3	3	1.072	1.151
Frequent	3.5	3	1.155	1.348
All	3	4	0.997	1.176

3.2.1. Objective results measured by Galvanic Skin Response.

The electrodermal activity data was processed by standard deconvolution analysis (nonnegative deconvolution), resulting in full decomposition of tonic and phasic components of GSR [1]. The sum of amplitudes of all significant reconvolved GSR for corresponding phasic driver-peaks (μS), with onset in the response window of each lane change maneuver, was then calculated. Data was tested and proved to be significant for multivariate normality with Kolmogorov-Smirnov goodness of fit test.

The results of the two-way ANOVA tests on the effects of 'frequency' and 'system', and their interaction on GSR are depicted in Table 3. Both 'frequency' and 'system' have a significant effect on GSR ($p\text{-value} \leq 0.05$). Fig. 6 shows the comparison of the marginal means of GSR sum of amplitudes (μS), indicating that the frequent group (left) and ASIS group (right) had less GSR response than the corresponding groups.

3.3. Annoyance

All answers from the participants on the measure of annoyance are depicted in Figure 7. The descriptive statistics are shown in Table 4. As the question for annoyance is phrased in a negative way (i.e., did you find the support system annoying?), the results

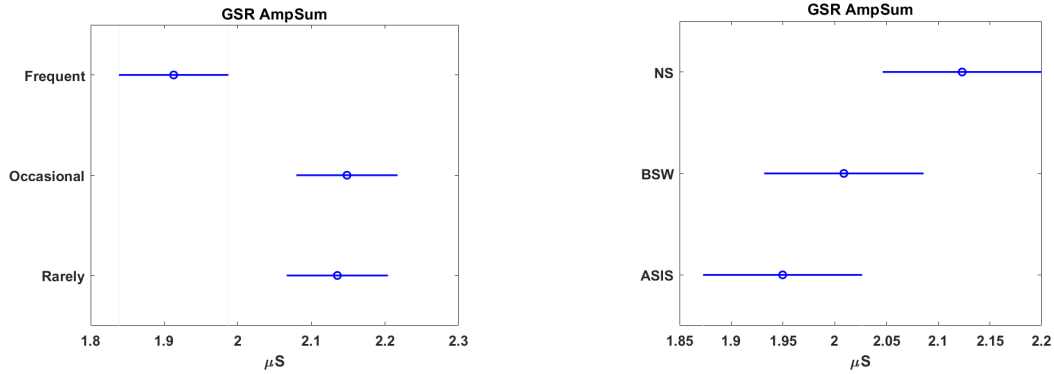


Figure 6. Multiple comparison of the mean of GSR AmpSum in microSiemens (μS) of groups: Frequency (left); System (right).

Table 3. 2-way ANOVA for the Sum of Amplitudes of Galvanic Skin Response.

	SS	DOF	MS	F	p-value
Frequency	15.85	2	7.9273	9.15	0.0001
System	7.72	2	3.8612	4.46	0.0118
Interaction (Frequency & System)	3.44	4	0.8607	0.99	0.4098
Error	1239.97	1428	0.8662		
Total	1264.14	1436			

need to be interpreted the other way around as the two measures above. Hence, a 2 is a supportive measure, while a 4 is a rather negative response (i.e., slightly agree that the support system was annoying).

The results indicate that ASIS was less annoying for rare drivers compared with BSW, while for frequent drivers there was indication that BSW was less annoying compared to ASIS. A first statistical analysis seems to confirm that the results for the group of rare drivers are statistically significant.

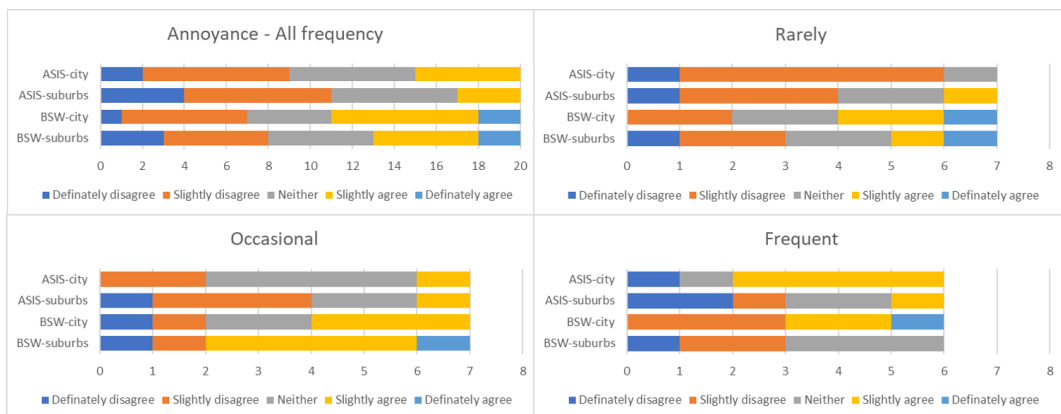


Figure 7. Overview of participant answers for annoyance.

Table 4. Overview of median and standard deviation for annoyance.

	BSW median	ASIS median	BSW S.D.	ASIS S.D.
Rare	3	2	0.877	0.616
Occasional	3	3	1.267	1.122
Frequent	2.5	3	1.422	1.030
All	3	2.5	1.187	0.986

4. DISCUSSION

We found that rare drivers feel it is easier to drive with ASIS support. We assume that rare drivers did not become accustomed to driving. Switching lanes is a difficult driving maneuver. Hence, ASIS seems to help drivers to perceive objects in the blind spot area by means of hearing naturalistic sound from the ASIS system. While ASIS uses a natural sound from the object, it also uses volume to indicate its distance. Furthermore, the distance at which support is activated is extended with ASIS, compared to BSW (37m instead of 15.4m). Hence, ASIS is not only providing support in the blind spot area, but also in an extended area. Extending this area and providing information about side objects earlier than BSW might have been the cause of such positive results for rare drivers. Occasional drivers, and frequent drivers in particular, might not need this extra time to get a full overview of the surroundings for changing lanes.

To support our assumption, participant’ free comments corroborate them. For example, a rare driver (participant 9) commented, ”It is easy to estimate the distance to the car behind in the next lane with ASIS than with BSW. I can concentrate on driving by looking ahead.” Another rare driver (participant 13) commented: ”The sound made driving easier. Because of the sound, the position of the car was estimated by hearing it.”

For the rare drivers group, we found an increase in the feeling of security. ASIS does not only provide information on the existence of obstacles in the blind spot, but also relates the object’s position and speed through an increase in volume, while BSW only indicates the existence of obstacles by lighting. These modality and informational differences might affect drivers’ sense of security. Using ASIS, participants could constantly perceive blind spot information by hearing if an object was approaching. On the other hand, participants must ”intentionally” check if the blind spot is safe or not. These differences might be due to the fact that rare drivers lack the resources to intentionally check the blind spots visually, while feeling more secure by passively receiving audio signals.

Our assumptions were corroborated by participants’ free comments. For example, a rare driver (participant 12) commented that: ”I felt that hearing was more appealing to the senses than seeing. I felt the sound indicator made driving easier”, and another rare driver (participant 17) commented that, ”It was good to know that the car was coming faster so that I knew I had to accelerate [to keep safer distance].”

The GSR level is lower for frequent drivers, which could explain our results. Because of this, they seem to have a better grasp of the surrounding and hence, probably need no additional support during lane change. For the rare and occasional drivers, the GSR level is significantly higher, which might explain why they felt better supported

(have an increased feeling of security) through ASIS, and rare drivers felt it is easier to drive.

5. CONCLUSION

This study investigated the benefits of intuitive auditory support on the awareness of hazards, a feeling of security, and its impact on feeling annoyed compared to blind spot warning and no support for blind spot. Our results indicate that, especially for rare drivers, intuitive auditory support is the system of choice and should be considered for personalization. ASIS supports an enhanced awareness of hazards so that participants feel it is easier to drive, increases the feeling of security, and seemed to be less annoying for rare drivers compared to BSW. Research so far shows that auditory support has the risk of being annoying. However, our results do not confirm this assumption. Our results indicate that ASIS is less annoying and reduces the GSR level for all drivers.

We found indications that frequent drivers prefer BSW to ASIS. However, more research is needed to fully understand the effect ASIS has on occasional and frequent drivers, as our results have shown no statistical significance compared to BSW.

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References

- [1] Benedek, M. and Kaernbach, C. (2010). Decomposition of skin conductance data by means of nonnegative deconvolution. *Psychophysiology*, 47(4):647–58.
- [2] Borowsky, A. and Oron-Gilad, T. (2013). Exploring the effects of driving experience on hazard awareness and risk perception via real-time hazard identification, hazard classification, and rating tasks. *Accident Analysis and Prevention*, 59:548–565.
- [3] Crundall, D., Underwood, G., and Chapman, P. (1999). Driving Experience and the Functional Field of View. *Perception*, 28(9):1075–1087.
- [4] Fagerlmm, J. and Alm, H. (2010). Auditory signs to support traffic awareness. *IET Intelligent Transport Systems*, 4(4):262–269.
- [5] Healey, J. and Picard, R. (2005). Detecting Stress During Real-World Driving Tasks Using Physiological Sensors. *IEEE Transactions on Intelligent Transportation Systems*, 6(2):156–166.
- [6] Patten, C. J., Kircher, A., stlund, J., Nilsson, L., and Svenson, O. (2006). Driver experience and cognitive workload in different traffic environments. *Accident Analysis and Prevention*, 38(5):887–894.
- [7] Scialfa, C. T., Borkenhagen, D., Lyon, J., Deschne, M., Horswill, M., and Wetton, M. (2012). The effects of driving experience on responses to a static hazard perception test. *Accident Analysis and Prevention*, 45:547–553.
- [8] Singh, R. R., Conjeti, S., and Banerjee, R. (2012). Bio-signal based On-road Stress

- Monitoring for Automotive Drivers. In *Proceedings of the National Conference on Communications*, pages 1–5, Kharagpur, India. IEEE.
- [9] Wang, M., Lyckvi, S. L., Chen, C., Dahlstedt, P., and Chen, F. (2017). Using Advisory 3D Sound Cues to Improve Drivers' Performance and Situation Awareness. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 2814–2825, Denver, Colorado, USA. ACM Press.