A method to improve driver’s situation awareness in automated driving

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Abstract

In the future, raising automation levels in vehicles is an imaginable scenario. However, there will be situations, which cannot be handled by the automation and the driver should take-over the driving task within a specific time budget. With a level 3 system (according to SAE), the driver no longer has to monitor the driving environment and, therefore, could perform other non-driving related tasks; consequently, leading to lower situation awareness (SA) and possibly worse take-over performance. In this paper, two versions of new visual advanced driving assistance systems are presented, which display subliminal information about the system states and confidence levels of the automation system. The goal is to increase the SA during automation and improve the take-over quality while allowing the driver to perform secondary tasks without distraction and annoyance. In this mixed design experiment, 32 participants performed a visual-motor task on a smartphone under 20 min automated driving with either one or another version of the new advanced driver-assistance systems (ADAS). Relative to baseline, the results showed some trends to significant improvements in the take-over quality and eyes on road time, especially for young or inexperienced drivers. The reported systems are currently in the process of being patented.

Introduction

Highly automated driving is currently one of the most discussed innovative topics and likely to become a series product within the next few decades (Gold, 2016). The development of driver assistance systems was based on the premise that the driver is continuously in the control loop supported by technical systems to conduct the driving task, which corresponds to level 1 and level 2. From level 3 automation (SAE) on, the driver does not have to monitor the vehicle while driving constantly (SAE J3016, 2016), which means the driver can conduct non-driving related tasks and be out of the control loop. Non-driving related tasks (NDRT) are for example eating, texting, talking, relaxing and so on (Pfleging, Rang, & Broy, 2016), which may lead the driver to divert attention from the driving scenery. This out-of-loop scenario may cause loss of awareness of the state and processes of the system (Endsley, 1995).
However, level 3 automation systems require the driver to react appropriately if the systems request this when reaching their system limit (SAE J3016, 2016), so called “take-over request” (TOR). Since situation awareness (SA) is critical to effective decision making and human performance in dynamic systems (Endsley, 1993), it is reasonable to help the driver’s mental model of the current system states and traffic situation to be updated, in other words, gain a higher SA, which supports an appropriate reaction in this time restricted situation.

**Situation Awareness**

Situation Awareness is a critical research theme in many domains, which involves human performance in dynamic or complex systems. It is widespread and exists in the military, air traffic, automobile driving and many more. There is no absolute definition and model of SA yet. Three different definitions and their associated theoretical perspectives dominate (Stanton & Young, 2000):

1) Three-level model (Endsley, 1995)
2) Perceptual cycle model (Smith & Hancock, 1994)
3) Activity theory model (Bedny & Meister, 1999)

The main difference lies in whether the SA refers to the process employed or to the product derived as a result of this process. The three-level model from Endsley comprised of three hierarchical levels describes SA as a product (Endsley, 1995). On the other hand, Smith and Hancock (1994) suggest the perceptual cycle model and define SA as adaptive, externally directed consciousness, which defines SA as a generative process of knowledge creation and informed action taking, not a snapshot of the agent's current mental model. Bedny and Meister proposed that SA is part of cognitive activity that is intensely dynamic (Bedny & Meister, 1999).

**Measurement of SA**

Salmon, Stanton, Walker, and Jenkins (2009) listed several SA measurement methods: SA requirements analysis, freeze probe technique, real-time probe technique, self-rating technique, observer-rating techniques, performance measures (direct / indirect), process indices (eye tracking), team SA measurefes.

Performance measures allow an indirect assessment of SA, which may be hits, crash avoidance during a simulated driving task or detection of hazardous events (Gugerty, 1997). Those measures are simple to obtain and are non-intrusive as they are generated through the natural flow of the task. It may be that efficient performance is achieved despite an inadequate level of SA, or that deficient performance is achieved regardless of a high level of SA. This has to be taken into account (P. Salmon, Stanton, Walker, & Green, 2006). Process indices involve recording the process in order to develop SA during the task under analysis, e.g. eye movement during task performance (Smolensky, 1993). The data can be used to assess which situational elements the participant fixated upon during task performance, and has been extensively used in SA assessment exercises (P. Salmon et al., 2006). The use of an eye-tracking device in the field is difficult but recommended for simulator studies. However, the disadvantage of “look but do not
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See” phenomenon should be considered (Brown & Great Britain. Department for Transport., 2005)

Goal

In the experimental study, different countermeasures to the loss of SA were developed, implemented and evaluated. The stimulation used should raise the SA of the driver to a certain level, which ensures a better take-over performance (red arrows in Figure 1). The stimulation should carry certain information to the drive, but it should not be a warning and not be annoying. The scenario is a level 3 automation (SAE J3016, 2016), which is defined as conditional automation.

Figure 1. SA drops during automated driving and the stimuli should help the driver have higher SA (modified from Toyota Motor Europe NV/SA)

Method

Stimuli Design

Visual, auditory, tactile, and haptic stimuli are applied to interactions between human and machine (Schenk & Rigoll, 2010).

To rate the suitability of a specific modality of a stimulus in the vehicle, Hoffmann and Gayko (2012) used the following categories: “content of information”, “coverage rate”, and “forgiveness rate”. In this work, a heuristic approach with various additional categories was conducted with two ergonomic experts. In addition to those mentioned above, the following categories are introduced concerning the usage and design purpose of the stimuli. These factors are the “perceptibility”, “interpretability”, “limitability”, “interference potential”, and “localisability”. Table 1 shows the evaluation result.
As evaluated in the Table 1, the visual channel can display very detailed and various information at once. It can be modified in many ways like varied colours, sizes or brightness, therefore “content of information” is [++]. The coverage is good overall but the visual capacity or visual attention might be limited by one or another scenario, therefore “coverage rate” is [+]. False alarms are quite forgivable because they are not as intrusive as other modalities. On the other hand, most visual stimuli can even be seen on the periphery and will be perceived, therefore “forgiveness rate” is [o]. The relevance or significance of information displayed can be perceived in most ways; in some use cases, the periphery would be ignored though, therefore “perceptibility” [+]. Since visual stimuli are modifiable in a lot of ways (format, brightness, colour, animation, etc), it can be designed with a very high interpretability, therefore “interpretability” is [++] . The period (time) as well as the area (space) of the stimuli can be designed very precisely with clear boundary, therefore “limitability” is [++] . The driver can decide to look or not or even ignore the given stimuli. Still, he/she will be peripherally stimulated in most cases by one or more visual stimuli, therefore “interference potential” is [+]. The feedback pointing at a specific scenario can be directly linked to events outside well in most cases. Still, the position of stimuli influences and limits its localisability, therefore “localisability” is [+]. As a result, visual stimulus is the suitable balance between information carrier and subliminal stimuli.

Furthermore in the literature, visual stimuli have some advantages over other modalities: the foveal perception (driving scene for the driver) will not be restricted...
by the stimuli in the periphery (Posner, 1980; Wickens, 2008). Visual perception in
the periphery does not need direct transition of attention (Maier, Kathrin; Sacher,
Heike; Hellbrück, Jürgen; Meurle, Jürgen; Widmann, 2011), which is on the
primary task. Information can be transmitted without an explicit concentration on
the stimuli (Utesch, 2015). Ambient light can catch the user's attention and raise
awareness for an upcoming event unobtrusively (Müller, Kazakova, Pielot, Heuten,
& Boll, 2013). Additionally, visual stimuli can be ignored on request so that the
stimuli could not be annoying. As a result, visual stimuli have been chosen
considering the requirements of raising the SA and not being annoying.

In this work, as a visual stimulus, an LED bar at the bottom of the windscreen is
chosen and implemented from the bottom of the left A-pillar to the bottom of the
right A-pillar of the static driving simulator (Figure 2). The 0.15 Hz pulse is defined
as the basic pulse, which should generate a calm and natural feeling and corresponds
to the frequency of the calm, natural human respiratory (9 times/minute) (Lehrer,
Vaschillo, & Vaschillo, 2000).

There are three different configurations of the stimuli:
   1) Pulse Only (PO): the frequency of the pulse is 0.15 Hz, the colour is white.
   (Figure 2)
   2) Pulse Event (PE): the frequency and colour of the pulse depends on the
      confidence level of the automation system. When the system is at its:
      a. high confidence level: the pulse is 0.15 Hz in white. (Figure 2)
      b. medium confidence level: the pulse is 0.50 Hz in white. (Figure 2)
      c. low confidence level: the pulse 0.50 Hz in blue. (Figure 3)
   3) Take-over Request (TOR): the frequency of the pulse is 1 Hz, the colour is
      red. (Figure 4)

Figure 2. White pulse, 0.15 Hz or 0.5 Hz
Hypothesis

The visual stimuli
1) …will be accepted by the participants in terms of modality, position, colour and frequency.
2) …will improve the reaction time (RT) after a take-over request.
3) …will increase the minimal time to collision ($TTC_{min}$) to a dangerous obstacle.
4) …will improve the manual driving directly after the take-over.
5) …will enhance the SA by increasing the eyes on road time/frequency.

Experimental Set-ups

To examine the hypothesis, a mixture within-between experiment was conducted. Two configurations of the stimuli are the between factors and the within factors are with stimuli or the baseline without stimuli. The sequences of all variance were all counterbalanced (Table 2).

Table 2. Experimental Design and counterbalancing

<table>
<thead>
<tr>
<th>Between (n=16)</th>
<th>Within (n=16)</th>
<th>Baseline</th>
<th>Pulse Only</th>
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<tr>
<td>Baseline</td>
<td>Pulse Event</td>
<td>Pulse Only</td>
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The experiment was conducted in the static driving simulator consisting of a complete vehicle mock-up. Seven projectors provided a front view of about 180 degrees as well as the views of all mirrors. The simulation software SILAB from WIVW (Würzburger Institut für Verkehrswissenschaften GmbH) was used to create the driving environment. The SILAB logs all relevant driving parameters and allows the LED-strip as well as the Dikablis 2 eye-tracking system to be controlled.

![Figure 5. Static driving simulator](image)

**Tracks**

To minimalise the learning effect, two different tracks and TOR scenarios were built. On the other hand, parameters like traffic density, time budget of the TOR and possible take-over manoeuvre are kept identical to ensure the comparability. Both tracks are 16 minutes long, the automation takes around 15 minutes. The route consisted of three parts (Figure 6). “Boring scenarios” simulates a monotony drive with occasional overtaking traffic as well as one overtaking scenario of the ego-vehicle. The second part has higher traffic density including manoeuvres around mobile construction vehicles. The third part contained a take-over scenario caused by system boundaries, in which the first hint of the danger appears when Time To Collision (TTC) is 7s while the TOR occurs with two-beep tone when TTC = 6s and the entire danger shows up.

![Figure 6. Test tracks with 3 parts and a TOR scenario](image)
Non-Driving Related Tasks (NDRTs)

Pfeging et al. (2016) identified several NDRTs that people will conduct in transportation. Apart from those, standard NDRTs are considered in this work concerning their controllability, reproducibility and clear separation of necessary modal resource. Table 3 shows the summary of some standard NDRTs and their characteristics.

Table 3. Analysis of standardised NDRTs

<table>
<thead>
<tr>
<th>Modality</th>
<th>Paced</th>
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<tbody>
<tr>
<td>Visual</td>
<td>Motoric</td>
</tr>
<tr>
<td>SuRT</td>
<td>X</td>
</tr>
<tr>
<td>CTT</td>
<td>X</td>
</tr>
<tr>
<td>n-Back-Task</td>
<td>X</td>
</tr>
<tr>
<td>20-Questions Task</td>
<td>X</td>
</tr>
<tr>
<td>Shape-sorter ball</td>
<td>X</td>
</tr>
<tr>
<td>DRT (Visual)</td>
<td>X</td>
</tr>
<tr>
<td>DRT (Haptic)</td>
<td>X</td>
</tr>
<tr>
<td>DRT (Acoustic)</td>
<td>X</td>
</tr>
<tr>
<td>Pointing Task</td>
<td>X</td>
</tr>
<tr>
<td>Counting/Calculating</td>
<td>X</td>
</tr>
<tr>
<td>Cognitive Task</td>
<td>X</td>
</tr>
</tbody>
</table>

The Surrogate Reference Task (SURT) (ISO/TS 14198, 2012) is a visual-motoric, user-paced task with various levels of difficulty, which was chosen in this experiment to simulate the daily smartphone usage. The participants should report an unusual item (target) in an array of similar items (distractor), usually an array of symbols, forms, colours or words. The similarity, which can be manipulated, influences the time for the participants to react. The more similar the distractors are to the target, the longer the reaction time is mostly. For the participant to be able to select the target, the display is divided into evenly distributed vertically arranged rectangular areas. The target is placed in one of those areas (ISO/TS 14198, 2012). This simulates a common use case of using a cell phone. To encourage participants to engage in the NDRT instead of monitoring automation, a real-time scoring bar was implemented on the screen, which shows the current performance of the user.

Measurements

Regarding the analysis of the SA measurement earlier, in this driving simulator study, performance and eye-tracking are evaluated as well as the acceptance of the subjects through questionnaires. The evaluation metrics include eye-tracking data before take-over scenarios, take-over time (Reaction Time (RT)), take-over quality, which consists of minimal Time To Collision (TTCmin) and Standard Deviation of Lateral Position (SDLP).
Results

The total number of participants in the study is 35. Because of technical problems during the experiment, there are 32 data sets available. As for eye tracking, due to technical failures on marker recognition, camera focusing and pupil detection, only 22 out of the 32 data sets could be analysed. There is no statistical significance ($\alpha = 0.05$) found in terms of TOR performance and eyes on road time (EoRT), since most participants had already performed very well. Nevertheless, in case of $0.5 < p < 0.1$, tendency to significance is reported.

Participant statistics

There were 7 female and 25 male participants. Average age was 25.63 years (SD = 4.43). All participants had a valid driving licence, mean = 8 years (SD = 4.10). 56% of them had already taken part in an experiment with a driving simulator, 22% even multiple times. 44% of the participants drove maximum 5,000 kilometres per year. 25% had between 5,000 and 10,000 kilometres; 22% between 10,000 and 20,000 kilometres. 60% had advanced or expert level knowledge of HAD/ADAS.

Driving Performance

Reaction Time (RT)

The reaction time is defined as the period, which starts from the TOR and ends with the first conscious engagement of the driver. Conscious engagement is present when the steering is turned (left or right) more than 2 degrees or the brake pedal is pushed over 10% of its maximum.

Comparing the mean RT of the baseline groups with both stimuli groups combined, no significant difference was found ($p = 0.2$). However, there is a descriptive smaller mean and smaller SD, which suggests a lower variance (Figure 7 left). Generally, most participants performed already very well in terms of reaction time (around 2 seconds) in the baseline.

The mean RT of the PO group showed a tendency to be significantly faster than its baseline ($p=0.095$). Additionally, the standard deviation is smaller. For the PE group, no significant difference was found ($p=0.98$) (Figure 7 right). Furthermore, PO helped 3 out of 4 “worst performers” (25th percentile) to get better, furthermore PE helped all the “worst performers” to improve their RT.
In addition, six subgroups are built according to the participants’ self-reported characteristics of themselves to compare the RT:

1) LED noticed or not: whether they have noticed the changing pattern of the Stimuli;
2) Driving simulator experience;
3) Drive experience;
4) Age;
5) Practical experience with Active Cruise Control (ACC)/Lane Change Assistance (LCA);
6) Knowledge about ADAS/Highly Automated Driving (HAD).

Because of the small number of subgroups, only the combined stimuli (PO+PE) are compared with the combined baseline. The stimuli showed a clear positive effect (less RT) for those participants:

1) …who have not actively noticed the stimuli. They also had a lower eyes on road time (EoRT), which means the stimuli had positively affected them in a subliminal way.
2) …who are younger (16-25 years old) and have less driving experiences (<5,000km/year).

Additionally, some small positive effects were found for participants with less simulator experience and no practical experience or knowledge about ADAS and HAD.

**Minimal Time To Collision**

The minimal time to collision is defined as the minimum value of all the TTC values within the measured time interval, for each time frame of measurement:

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1 All error bars in the diagram in this work are standard deviations.
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\[ \text{TTC} = \frac{v_{\text{ego}} - v_{\text{obstacle}}}{\text{distance to obstacle}} \quad \text{(when } v_{\text{ego}} > v_{\text{obstacle}}) \]

In cases of \( v_{\text{ego}} \leq v_{\text{obstacle}} \), \( \text{TTC} = \infty \). Having a lower minimal TTC complies with a bad take-over performance (higher danger).

In this work, the measurement interval starts from the TOR until the last moment when the centre of the car crosses the lane mark, if there is a lane-change manoeuvre, which is demonstrated as the red arch in Figure 8.

\[ \text{Figure 8. Demonstration of the calculation of } \text{TTC}_{\text{min}} \]

Comparing the \( \text{TTC}_{\text{min}} \) performance of the combined baselines with both stimuli combined, no significant difference was found (\( p = 0.87 \)) (Figure 9 left). For the same reason as the RT, participants could not improve much since with a \( \text{TTC}_{\text{min}} > 2 \) s the performance is already very good and they are far from danger.

For the specific analysis, \( \text{TTC}_{\text{min}} \) of the PO group showed no significant difference (\( p = 0.37 \)) to the baseline, but a higher mean and a much smaller SD (Figure 9 right). Additionally, no significant difference for the PE group was found (\( p = 0.31 \)), but a slightly lower mean with similar SD, which indicates even a negative effect of the PE stimuli. The explanation could be that participants reported that they misunderstood the stimuli as a warning system, which will warn them in any dangerous case, which may lead to over trust, and a delayed reaction to the danger, therefore smaller \( \text{TTC}_{\text{min}} \).

In the “best/worst performers” analysis, PO increased all TTCs to at least 2 s: “worst performer” (TTC < 2 s) all got better and passed the 2 s TTC mark. Some good performers got worse but only because they were already at a very good level (still > 2 s TTC). PE helped the worst performing participants (TTC < 2 s) to get better or not worse. However, most good performing participants (TTC > 2 s in the baseline) got worse, one participant had below 1 s TTC and one crashed in the PE condition.
Figure 9. Comparison of \(\text{TTC}_{\text{min}}\). Left: PO and PE combined as LED; right: PO and PE groups.

Like the subgroup analysis of the RT, the stimuli showed again a positive effect to \(\text{TTC}_{\text{min}}\) for:

1) …those who have not actively noticed the stimuli (≈subliminal).
2) …those who are younger (16-25 years old) and have less driving experiences (<5,000km/year).

Additionally, some smaller positive effects were found for participants with less simulator experience and no practical experience or knowledge about ADAS and HAD. Slightly negative effects were found for participants with much driving experience and theoretical and practical knowledge of ADAS and HAD. This could be due to participants considering the PE (and PO) as a warning system, since they were familiar with many ADAS systems as they claimed.

**Standard Deviation of Lateral Position (SDLP)**

SDLP, an index of ‘weaving’, is a stable measure of manual driving performance with high test–retest reliability (Verster & Roth, 2012). The lateral position in this work is a value of the distance \(d\) (Figure 10) between the centre of the ego vehicle and the middle of the driven lane. Since it’s not meaningful to calculate the SDLP when lane changing, the measurement intervals therefore start after the lane change process has finished, which is defined when the centre of the ego vehicle is at first closer to the middle of the 2\textsuperscript{nd} lane than 0.1 m. The measurement will last for 5 seconds due to the length of an overtaking process.
In the SDLP analysis, n=17 because it includes only those who changed lane to the middle lane in both trials (for baseline and PO, n=7; for baseline and PE, n=10).

Between the baseline and stimuli (PO/PE combined), there was no significant difference (p = 0.27) (Figure 11 left). Still, the descriptive mean of the SDLP with the stimuli is smaller and the SD is slightly smaller too (Figure 11 left).

**Standard Deviation of Lateral Position**

The PO condition showed a descriptive lower mean of SDLP with lower variance but no significance, which is similar to PE (Figure 11 right).

Both stimuli conditions showed a tendency towards better manual driving directly after TOR but there is no significance due to the number of participants.
Eye-tracking

As showed in Figure 12, three different Areas Of Interest (AOIs) were investigated:

![Figure 12. Demonstration of AOIs](image)

1) Blue area: road, driving scene. This is to check the eyes on road time (EoRT).
2) Purple area: Tablet screen of NDRT: Sony Xperia Z Ultra, 6.4 inches tablet. This is to check how well they engaged in the NDRTs.
3) Yellow area: left side mirror. This is to check the quality of the take-over manoeuvre, how well they check the left lane before changing lane.

The first measurement interval starts from activation of the automation until the TOR (about 14 min). The second measurement interval starts from the TOR and lasts 10 seconds under the consideration of period including take-over manoeuvre and over-taking manoeuvre. The third measurement is the time until the first glance on the road after TOR. The recorded data are the following three:

1) Total glance time in [%] or [sec] is defined as the sum of all time on a specific AOI.
2) Mean glance duration in [sec] is the mean time of each glance on a specific AOI.
3) Number of glances is the total number of glances on a specific AOI.

Generally, 13 out of 22 participants’ percentage of EoRT increased to a meaningful level with LED, 5 of them did not change much. There are four participants that looked much less at the road with the LED, which had all the same LED conditions as the first trial, which may be probably due to a strong sequence effect.

It is found that the participants looked more often and longer at the road in the second trial regardless of being with or without stimuli. Because of this “sequence effect”, only the eye tracking data from first trials of each participant will be investigated.

In Figure 13 (left), there is a tendency to a significant longer “mean glance duration on the road” (p = 0.07). The total glance time on the road shows a higher mean but
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no significant difference (Figure 13 (middle)), 3 participants as outlier (16.3%; 22.3%; 31.4%) are out of consideration. Finally, the mean of the number of glances on the road increased as well but without significance (Figure 13 (right)), 1 participant as an outlier (340) is out of consideration. These facts indicate with stimuli, participants tend to watch longer for each glance and longer in total and more often at the driving scene, which is a way to gain higher SA.

Figure 13. Comparison eyes on road data in three aspects, PO and PE combined

This is also supported in Figure 14, both stimuli (PO and PE) increased mean glance duration, as well as the total glance time and number of glance.

Figure 14. Comparison eyes on road data in three aspects, PO and PE separated
In addition, novice (< 5,000 km/year) and young drivers (16-25) showed no change in glance patterns, seem not to be affected by the stimuli while experienced (both 5,000-10,000 km and > 10,000 km groups) and older drivers (26-37) increased their mean glance duration on the road by using the stimuli and therefore they had a better chance to gain higher SA. That might because of the over-trust (in automation) of young and less experienced driver due to less expertise of dangerous situations.

Furthermore, as expected, eye tracking data does not correlate well with driving performance. Participants with bad RT did not have lower EoRT than those who performed well. The “Look but not see” problem occurred.

**Subjective Evaluation**

A questionnaire after each experiment about the colour, position, frequency, and visual modality of the stimuli indicates that:

1) **Colour**: 93.75% of participants rated white for the constant stimuli in the “automation mode” as (very) proper, 62.5% of participants are for the blue stimuli when events occur, finally 100% rated red very proper for the TOR. When alternatives were asked, it’s reported green could replace white, and yellow could be used instead of blue, because they understood the stimuli as a warning system, and therefore they were strongly influenced by the traffic light colour concept.

2) **Frequency**: In the PO condition, 87.5% of participants rated the frequency of 0.15 Hz for the white pulse at least as properly designed; 93.75% rated the 1 Hz red pulse at least as proper. In the PE condition, 75% of participants rated the frequency of 0.15 Hz for the white pulse (high confidence) at least as properly designed; 68.75% are for the 0.5 Hz white pulse (medium confidence); 68.75% are for the 0.5 Hz blue pulse (low confidence); 100% rated 1 Hz of the red pulse (TOR) at least as proper.

3) **Modality**: 94% prefer visual modality in such application.

4) **Position**: 88% think that the applied position of stimuli (as Figure 3-5) is (very) proper.

5) **Acceptance**: 75% of participants would wish to have such a system (PO as well as PE) in an automated vehicle. Reasons such as the system supports them to understand the situation; helps to build trust; allows passengers also to be aware of the system states regardless of the weak and ignorable intensity of the stimuli were mentioned for PO. Reasons such as the feedback of events helps build the trust, which would relieve the driver from the monitoring task, was mentioned.

**Limitations**

Due to the small number of participants (n=32) and many test variances of concepts (baseline, PO and PE) on different conditions (track 1 and track 2), the results are not statistically significant. The stimuli itself could be regarded as warning system, but then too weak, too regular and too general as warning. Due to its position, the stimuli may not be perceived when the driver conducts NDRTs. The PO version might be perceived as monotonic and therefore be superfluous and useless.
Conclusion

There is no statistical significance in terms of TOR performance. However, the stimuli did help the worse drivers to shorten the gap. Specifically, the stimuli (PO+PE):

1) ...had a high acceptance in terms of the modality, position, colour and frequency.
2) ...helped bad performers to improve with the RT and increase the TTC.
3) ...showed a positive effect (better RT and TTC) in this sample for participants who reported having not noticed the LED (≈ subliminal), having less simulator experience and no practical knowledge about ADAS and HAD compared with those who had.
4) ...improved the manual driving directly after the take-over (SDLP).
5) ...increased the mean glance duration, eyes on road time and number of glances.

It seems that in this study the PO condition was slightly better than the PE one. This might be due to participants misinterpreting the stimuli as a warning system (and not a likelihood information), which might lead to over-trust.

Overall, the stimuli showed a high potential to raise driver’s SA and to improve possible take-over performance without annoying the driver. Adding an additional modality such as auditory or haptic for a multi-modal approach might improve the performance even more.

Acknowledgement

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References


