Traffic Light Assistant - What the Users Want

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***Abstract*—In a driving simulator experiment, a prototypical traffic light phase assistant is assessed. The main research issue: How would a user customize the system? As a sideline, data is gathered with a special Detection Response Task (DRT), the *Tactile Detection Task (TDT)*, in conjunction with an auditory cognitive task as reference. Recorded gaze data, driving behavior, subjective ratings with a *System Usability Scale (SUS)* and an *AttrakDiff2*-questionnaire are also reported. The subjects were able to customize ten parameters of the traffic light assistant system. The so personalized system configuration showed no great enhancement in the subjective ratings; thus, the later application implementation will include only little configuration features for the user. However, the test persons exhibited a willingness to be informed about speeding by a speed alerting function within the traffic light assistant system. The performance (reaction time) of the TDT is interpreted as a measure for the cognitive load while using the interface. The auditory cognitive task prolonged the reaction times for a tactile detection task more than the traffic light information system. The glance times are in line with current guidlines and the driving behavior shows a potential benefit for safety. Thus, the reported experiment evaluates an interface for use while driving with objective metrics regarding distraction and subjective results related to usability and joy-of-use.**

Keywords-in-vehicle information system*; *IVIS*; *nomadic device*; *tactile detection task*; *TDT*; *glance duration

I. INTRODUCTION

In the project KOLIBRI (Kooperative Lichtsignaloptimierung – Bayerisches Pilotprojekt; engl: cooperative optimization of traffic signal control), the Institute of Ergonomics at the Technische Universität München was responsible for the human factor of a traffic light assistant. One of the goals of the project was to provide the driver with information about the state of an upcoming traffic light.

By introducing a traffic light assistant for smart phones, previously installed 2nd and 3rd generation telecommunication networks (e.g., Global System for Mobile Communications, GSM) could be used to transmit the information. Nowadays smart phones are widely used, so there are no extra costs to get an additional display into the car. With a mobile solution, instead of an in-vehicle implementation, there is also no limitation regarding the make, year or brand of the car.

In this project, the traffic lights were equipped with mobile network transponders to send their current state to a central server. The server estimates how the traffic lights will probably act the next time. These estimated switching times can be polled by car systems or smart phones. The devices have to calculate recommendations, based on human factors, and show appropriate information to the driver. Because they are used while driving, special care must be taken for suitability while driving [1].

The system was implemented in two real test fields. The first is in the north of Munich. Over a length of about seven kilometers, seven traffic-light-controlled intersections on federal road B13 were involved. The second test track was a rural road near Regensburg. Over a length of about five kilometers, eight traffic light controlled intersections shared the system.

In order to make a judgment about safety issues, the test track in the north of Munich was modeled for the static driving simulator at the Institute of Ergonomics and was used in an initial subject test [2], [4]. The test persons evaluated five rapid prototyped Human Machine Interfaces (HMI) with standardized subjective questionnaires and wore an eye tracking system. The HMIs were shown on a smart phone and were coupled with the driving simulator. The results led to a favorable HMI within the project, and the gaze behavior showed no critical metrics for this HMI.

In the second driving simulator experiment, reported in this paper, subjects were told to customize the assistant to their needs by adjusting some parameters. The main idea: What aspects must be configurable (e.g., what are potential items on a configuration menu in an application). The test persons also wore an eye tracking system here. In addition, a special Detection Response Task (DRT), the Tactile Detection Task (TDT), was operated. DRTs are currently being standardized and are promising candidates to get objective data for the mostly invisible cognitive load.

The next section presents related work for this paper in the fields of traffic lights assistance and detection response tasks. The method section holds information about the conduction of the experiment. The design of the experiment, technical data of the driving simulator and the traffic light assistant as well as the details of the cognitive task and tactile detection task are reported. The method section closes with the task instruction and demographic data of the participants. The result section shows how the participants would customize

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the traffic lights assistant and their performance in the tactile detection task. Subjective data from questionnaires compares the liking of the individually customized (HMI) with a default HMI. The section closes with the presentation of glance durations and driving behavior metrics.

II. Related Work

A. Traffic Light Assistance

Early research in the field of in-car traffic light assistance took place in the '80s in the project *Wolfsburger Welle* from Volkswagen, Germany [5], [6]. At about the same time, Australian traffic engineers experimented with a roadside traffic light assistant along a street in Melbourne [7], [8]. These projects evaluated and identified the benefits for the informed driver, such as fuel reduction. To provide information about the traffic light to the driver, with countdowns, is common in some countries, mainly in Asia. Many people have reflected about this topic, so different solutions for traffic light information can be found in patent classes such as *G08G 1/096*. The advantage of roadside solutions is that everyone can use them. The disadvantage, other than maintenance costs, is an only temporally visibility, or else several must be placed along the road. Another problem is reported by [9]: Counting down the remaining green time at an intersection results in a higher crash risk.

Pauwelussen et al. [10] compared a road side system with an in-car system and found objective reasons for using an in-car system and subjective reason for using the roadside signs. Thoma [11] evaluated various HMIs for an in-car on-board system and proposed a combination that would work with the speedometer. Another project dealing with on-board traffic light guidance is TRAVOLUTION from Audi AG, Germany [12]. A traffic light phase assistant was also included in the German car-to-infrastructure project *simTD* [13]. The German project *AKTIV* built a traffic light assistant on a personal digital assistant (PDA) via WiFi [14], [15]. Another project that used a mobile device for a traffic light assistant is *SignalGuru* [16]. This project heavily relies on the camera of a smart phone on image processing. One radical idea that also involves traffic light assistance is to replace the physical traffic lights with in-car information i.e., Virtual Traffic Light (VTL) [17].

B. Detection Response Tasks (DRTs)

In detection response tasks, the test persons have to react to a continuously repeated stimulus. Typically, this detection task is the 'probe' i.e., a measurement tool to asses the demands of another task or combination of tasks, like interacting with a system while driving a car. The prolongation of reaction times and a drop in the rate of successfully fulfilling these detection tasks are potential indicators for the cognitive load. The DRTs are currently being standardized by the *ISO TC22 SC13 WG8*. In former work and projects, the detection tasks had shown the potential to detect cognitive load effects. The use of a vibration stimulus (tactile detection task, TDT) overcomes various disadvantages such as the visibility of a light stimulus under changing lighting conditions and has, if at all, only a weak competition and distraction effect on visual resources. A commendable review of the research on TDT can be found in [18].

III. Methods

A. Experimental Design & Procedure

Each subject drove for each part of the experiment (within design). The test persons first completed a letter of consent and a demographic questionnaire. Afterward they get general explanations about the experiment and the driving simulator. Once they were seated in the mockup car, the gaze tracking systems was calibrated for each person. The subjects drove an acclimatization round without the traffic light assistant and one round with the system (in configuration *complex*). Before and after the core of the experiment, the TDT was carried out alone (single task) for one minute (*TDT_base1* and *TDT_base2*). In the core of the experiment, four parts were completed in randomized order:

- *Baseline*: Driving the simulator without the traffic light assistant and with TDT
- *COTA*: Driving the simulator without the traffic light assistant, but with a cognitive task (COTA) and with TDT
- *HMI complex*: Driving the simulator with the traffic light assistant in a general, predefined configuration and with TDT
- *HMI individual*: Driving the simulator with the traffic light assistant in a personalized configuration and with TDT

Before the *HMI individual* part, the test subject was able to customize the HMI using ten parameters, and was allowed to drive and test the interface as long as needed. After the *HMI complex* and *HMI individual* sections, the subjects filled in a system usability scale (SUS [21]) and AttrakDiff2 questionnaire [22]. The test track (about 7km) was randomly driven in a north-south or south-north direction. A session typically lasted about 90 minutes.

B. Driving Simulator

The simulator track is a model of a real road section of the federal road B13 in the north of Munich (see [2], [4]) which is also the test bed for real field trials in later experiments. The experiment used the institute's static driving simulator. Three projectors (1400x1050 resolution) show an almost 180-degree front view on 3.4 m x 2.6 m screens. Three other projectors displayed images on screens behind the BMW E64 mockup for the car mirrors. The driving simulation SILAB V3.0 from WIVW GmbH, Würzburg was used together with CarSim V7.11 from Mechanical Simulation, Ann Arbor, as well as an active steering wheel with software from Simotion, Munich. For the eye tracking, the head-mounted system Dikablis from Ergoneers, Manching was used. Gaze analysis was carried out with D-Lab (Ergoneers, Manching) and Matlab.

C. Traffic Light Assistant - Human Machine Interface, HMI

In an initial simulator experiment [2], [4] an appropriate HMI was found to communicate a speed recommendation to the driver via the smart phone (called the *velocity carpet*; see Figure 1, left). If the driver has to move to slowly (below 70% of the speed limit) or too fast to get the next traffic light on green, Figure 1 (middle) is displayed, called *red arrive*. Both conditions (too fast, too slow) are intentionally coded into the same screen, to prevent the misuse of the system. In addition, some new parts were introduced: A circle (left upper corner of Figure 1, left) could provide information about the current cycle state of the next traffic light (called *Heuer traffic light*). A distance bar (right border of the screens in Figure 1) indicates the meters remaining to the next traffic light. A speed alert (Figure 1, right) provides a warning in the event of speeding.

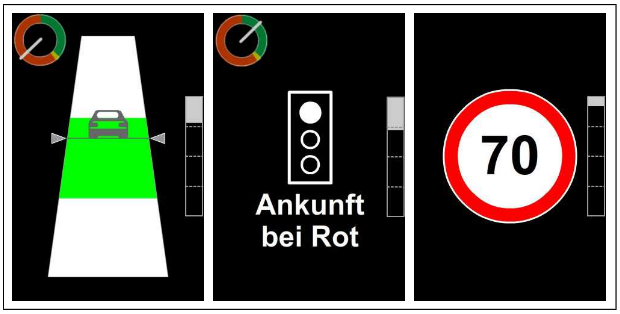

Figure 1. Traffic Light Assistant, Human Machine Interface screens. left:carpet, middle: 'Ankunft bei Rot' = arrival on red, right:speeding

In this experiment, the test persons were able to customize different parameters of the system and test their customized systems directly in the simulator (known as *HMI individual*):

1) the velocity carpet could be switched off (black screen) *[carpet **on**/off]*
2) the velocity carpet could only appear if the distance to the next traffic light is less than X meters, or it can be on all the time *[carpet distance X meters ./. **100%**]*
3) either arrival on red could be displayed, or a blank screen*[arrival on red **on**/off]*
4) *[speed alert **on**/off]*
5) the speed alert could inform the driver if the car is going X km/h above the speed limit *[speed tolerance X km/h]*
6) the Heuer traffic light could be displayed *[Heuer **on**/off]*
7) the distance bar could be displayed *[distance bar **on**/off]*
8) while waiting at a red light, the residual red light time could be displayed *[residual red **on**/off]*
9) when driving through an intersection, the system output could be suppressed (Xing symbol) *[Xroad suppression on/**off**]*
10) when intersection suppression is on it should suppress system output X meters in front and after an intersection [*intersection radius X meters*]

The order of the single parameters for the customization was randomized. The system was also driven in a uniform configuration by all subjects (known as the *HMI complex*). This configuration consisted of the bold options in the previous enumeration and a speed alert tolerance of 0 km/h.

D. Cognitive Task, COTA

For the cognitive task, the program *Cognitive Task 1.0* from Daimler AG (Stefan Mattes) was used with default settings. The program reads a sequence of three numbers (one to nine) out loud, and after a short break a fourth number is announced. The task of the test person is to consistently state whether the fourth number was included among the first. Two examples: Program: *'2,6,9...7'*. Test person: *'No'*. Program: *'7,1,3...1'*. Test person: *'Yes'*. So it is an auditive Sternberg Task. The chosen setting plays a beginning chime sound (about 1s), reads out three numbers (one per second), waits 2s, plays a chime sound (about 1s), announces the forth number (1s), the test person has 3s to answer and at the end the program plays a short closing honk signal and wait 2 seconds before beginning the next sequence. The repeat count was set up to repeat the described 13-second sequence over and over again during the whole 7 km ride on the simulator track (typically about 6 minutes). The voice of the test person was recorded and evaluated after the session.

E. Tactile Detection Task, TDT

For the TDT, a self-made device with an Arduino Uno was used. The device was set to a vibration stimulus randomly distributed from 3 to 5 seconds. The test person has to react within 2 seconds after stimulus onset, else it is a *miss*. The stimulus lasts one second or until the subject reacts. If the reaction time (RT) is lower than 200ms it is canceled a *cheat*. RTs between 0.2s and 2s are *hits*. The metric *hit rate* is the number of hits divided by the number of stimuli (see [18], [19]). As proposed by [19], a data set must have a hit rate of at least 70% to be included for data analysis. The device was programmed internally to react interrupt based on subject's reaction. The standard Arduino Uno clock resolution of 4 microseconds was estimated to be enough to measure milliseconds.

The vibration stimulus was applied via a vibration motor from an old mobile phone (Alcatel One Touch Easy 302) at an open clamping voltage of 4.2V (2.8V under load) with 22mA. The motor was attached to the right wrist with a flexible wristband (figure 2), vibrating at about 125 Hz. For the reaction, a micro switch was glued to the back side of the

Figure 2. Setup of the devices in the driving simulator

steering wheel at the 10 o'clock position (the track included no sharp curves or overtaking).

F. Instruction

The participants were instructed to give the driving task the highest priority. Their second priority was the detection task. Finally, they were to concentrate on using the HMIs or the *COTA*.

G. Participants

Twenty-two test subjects took part. One quit due to simulator sickness, so the data set is not regarded. The data for one test person revealed that she (healthy young female) probably did not use the vibration stimulus onset for the reaction in some experiments, else the automatic switch-off was interpreted as stimulus signal, unnoticed by the experimenter. Their data set was ignored for the TDT calculations.

The age of the test subject was from 20 to 32 years (M=25.1, SD=3.1). Two females took part. All of the test persons had normal or corrected to normal visual acuity (43% used corrective lenses during the experiment). Three had a color perception deficiency. The average annual milage was 11,486 km (SD 11,825). Ninety percent had driven an automatic car (like the driving simulation car) before. Previous experience with a driving simulator was reported by 76%. 19% of the test persons took part in the first experiment for a traffic light assistant at the institute [2], [4].

IV. Results

A. Customization

- Parameters: *[carpet on/off]* & *[carpet distance X meters ./. 100%]* All of the test subjects enabled the speed recommendation. Nineteen of the twenty-one subjects wanted to be informed about the carpet whenever possible. One person specified 300 meters in front of the traffic light and another person 1000 meters before.
- Parameter *[arrival on red on/off]*: 57% preferred to be informed that they would probably arrive at red, instead of a blank screen.
- Parameter *[speed alert on/off]* & *[speed tolerance X km/h]*: 71% enabled the speed alert at an average speed tolerance of 17.5 km/h above the allowed speed limit.
- Parameter *[Heuer on/off]*: 62% of the subjects selected the Heuer traffic light option for their individual HMI.
- Parameter *[distance bar on/off]*: 62% wanted the distance bar in their customized HMI.
- Parameter *[residual red on/off]*: 91% wanted to be informed about the remaining red light time while waiting at the traffic light.
- Parameter *[intersection suppression on/off]* & *[intersection radius X meters]*: Three person selected the suppression of system information at intersections at radiuses of 100, 150 and 200 meters.

B. Tactile Detection Task, TDT

The TDT results were only included for a person in an experimental section if the hit rate was above 70% (see [19]). For *COTA*, two data sets do not meet this quality criterion, and one data set for *HMI complex*. A statistical test reported no significance between the reaction times (Figure 3) of *Baseline*, *HMI individual*, *HMI complex* and *COTA*). In the *COTA* condition, the *COTA*-software pronounced on average 26.5 challenges. 99% of these were answered correctly. This shows that the subjects were all engaged in doing the cognitive task.

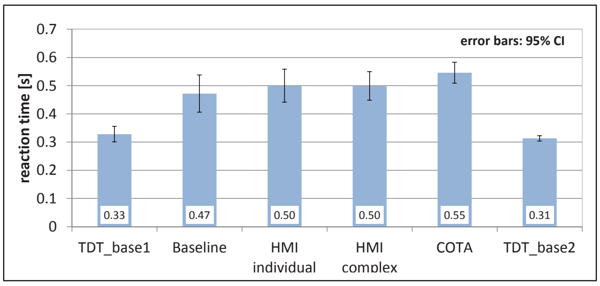

Figure 3. TDT reaction times

Figure 4 shows the hit rates under different conditions (data sets with a hit rate lower than 70% were also included). A statistical test reported no significance between *Baseline*, *HMI individual*, *HMI complex* and *COTA*).

C. System Usability Scale, SUS & AttrakDiff2

The system usability scale (SUS) reported:

- *HMI complex* 72.6 (SD 12.6)
- *HMI individual* 73.9 (SD 12.9)

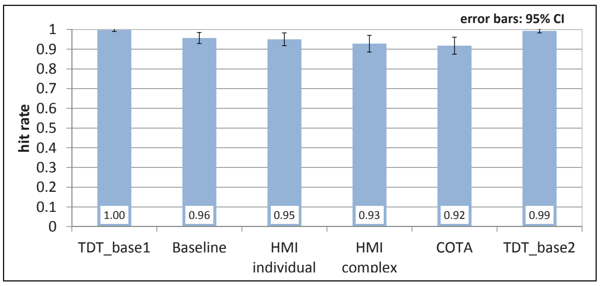

Figure 4. TDT hit rates

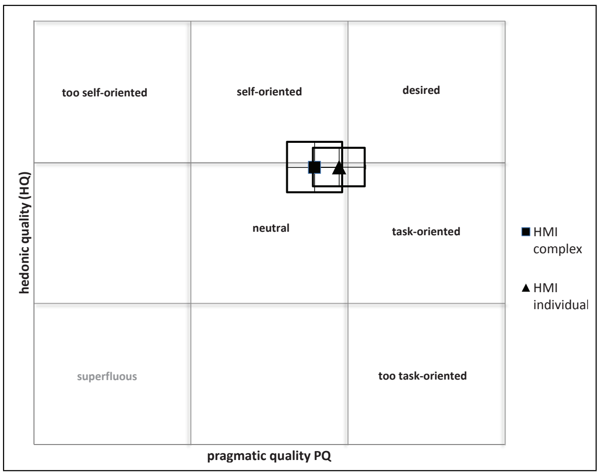

Figure 5. AttrakDiff2 portfolio diagram with confidence rectangles

The attractiveness dimension (scale from 1 to 7) of the AttrakDiff2 reported

- *HMI complex* 4.7 (SD 0.6)
- *HMI individual* 4.9 (SD 0.9)

The other dimensions of the AttrkDiff2 are shown in a portfolio diagram (Figure 5).

D. Gaze Behavior

For the first analysis the gazes were exported from D-Lab to Matlab. In Table I and Table II, the gazes of all test subjects are handled as a whole. Thus, a reported 85th percentile value (p85) or mean value (avg) is the p85 or mean value of the number (N) of gazes. The table only includes values for gazes, while the smart phone showed a speed recommendation (*velocity carpet*) and all other conditions are initially neglected (arrival on red, residual red, etc.). The average frequency (fq) is the entire duration of the *velocity carpet* condition divided by the number of glances by all subjects. In the *baseline* run, only 3 gazes toward the AOI *smart phone* are recorded, in *COTA* 8. So no avg and p85 values are reported. Accordingly, the eyes-off-the road incidents are mainly *speedometer* gazes. For the *eyes-off-the-road* values, the gaze durations not directed toward the windscreen are evaluated. In the conditions *baseline* and *COTA*, the display of the smart phone is blanked out (black), but in order to get segments for comparison, the smart phone nevertheless reports to the eye tracking system whether a *velocity carpet* would have been shown. The percentage of time (%) is calculated: frequency (fq) multiplied by mean glance (avg)

TABLE I. GAZES TOWARD THE SMART PHONE

	N	fq [Hz]	avg[s]	p85[s]	%
Baseline	3	0.001	n.a.	n.a.	n.a.
HMI individual	1072	0.275	0.64	0.88	17.5%
HMI complex	802	0.259	0.65	0.91	16.9%
COTA	8	0.004	n.a.	n.a.	n.a.

TABLE II. EYES OFF THE ROAD

	N	fq [Hz]	avg [s]	p85 [s]	%
Baseline	410	0.272	0.69	0.92	18.7%
HMI individual	1580	0.406	0.85	1.20	34.3%
HMI complex	1240	0.400	0.82	1.20	33.0%
COTA	516	0.256	0.68	0.88	17.3%

For the *HMI complex* run, D-Lab reported a mean gaze duration of 0.61s and a gaze frequency of 0.20Hz, if the smart phone showed the *arrival on red* screen. In addition, for *HMI complex*, a mean glance duration of 0.38s can be derived for the speed alert screen from D-Lab (with an average frequency of 0.24Hz). In *HMI complex* (zero speed level tolerance for speed alert system), the eye tracking system logged a mean total duration for speed alerts of 80s per run (mean duration of run: 348s). So the test subjects drove about 23% of the time with a ‘nag screen’.

E. Driving Behavior

The time that each driver drove above the speed limit was set in relation to the time the car was moving faster than 5km/h. The average of these percentage values for each person’s run can be seen in Figure 6.

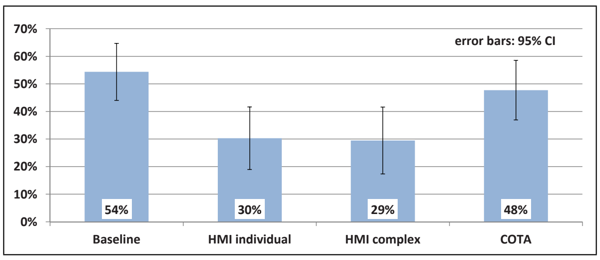

Figure 6. Average percentage of time (while car moving >5km/h) above speed limit

For Figure 7, the excess speed beyond the limit was treated as root mean square value (RMS). Values below the speed limit were treated as zero. The average speeding RMS of the test subjects’ single runs is reported.

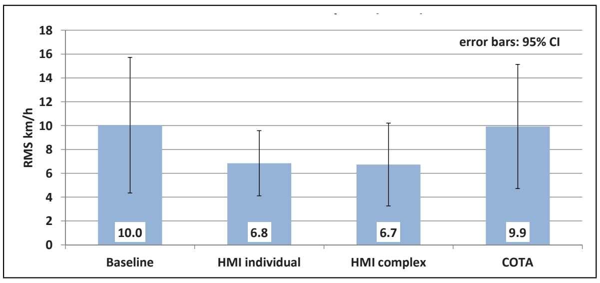

Figure 7. Average RMS value above allowed speed (km/h)

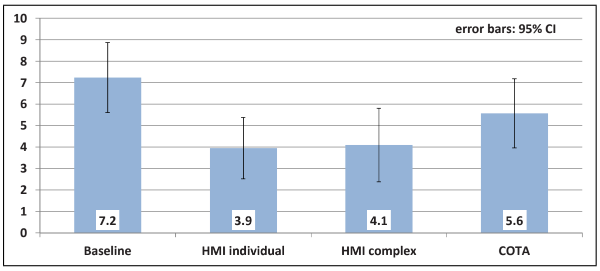

Figure 8. Average number of speed violations

The person's speed violation counter was triggered if the speed exceeded the allowed value by >15km/h. After a detection, the next re-triggering for a rising edge above 15km/h is inhibited for 10s. The average value for the single test person's run can be found in Figure 8.

V. Discussion

The customization shows that the test persons wanted the speed recommendation, not at a fixed distance, but whenever possible. More than half of the test subjects also wanted to be informed whether they would arrive on red. About two-thirds enabled the speed alert. This acceptance is probably closely coupled with the high average tolerance speed of 17.5 km/h. If one take into consideration, that the square of speed is included in kinetic energy (crash), the speed estimation in reality will likely come from a 1Hz GPS receiver, and German law enforcement on rural roads will most likely use a tolerance level of about 12-14 km/h; the value of 17.5 km/h is too high. A tolerance level of 10 km/h, which might work in reality, was accepted by one-third of the test subjects and was implemented for later tests on real roads. The Heuer traffic light sign and the distance bar had a popularity level of over 50%. A later expert review revealed that there would be too many moving and animated screen objects. It was decided to drop the distance bar in order to get a clearer presentation. The remaining red light time while waiting was enabled by over 90%. That is positive indicator for acceptance. The option to suppress system information in intersection areas was not used by 85%. That is a clear sign of rejection.

The TDT results from *TDT_base1* and *TDT_base2* are very close. The reactions from *TDT_base2* are a little bit faster. So, learning effects and fatigue did not play an important role or cancel each other out. The standard deviation (and thus the related confidence interval) for *TDT_base2* gets very small. This indicates that at the end of the experiment there is not much intersubject difference. Reaction times and hit rates show a plausible order: *Baseline* imposes the lowest cognitive load. *HMI individual* and *HMI complex* are about equal, and a little bit more mentally demanding than *Baseline*. The cognitive most demanding condition appears to be *COTA*.

The SUS values of *HMI complex* (72.6) and *HMI individual* (73.9) are very close. The individual customization is not reflected by a high gain in the subjective usability scale rating. According to [20], both of the SUS values reported here, can be associated with the adjective *good*. In the first simulator study without the TDT [2], a nearly equal value of 75.3 was found. The slight drop may be is influenced by the TDT. The attractiveness dimension of the AttrakDiff2 (from 1 to 7) also reports only a minor change between *HMI complex* (4.7) and *HMI individual* (4.9). The value from the first experiment [2] was 5.0. The portfolio diagram shows that the hedonic quality for *HMI complex* and *HMI individual* are at the same level, but the pragmatic quality is rated a little bit higher for *HMI individual*.

Often, the 85th percentile value for the glance duration is calculated using the 85th percentile of the mean values for the test subjects. The maybe more conservative way, obtaining the 85th percentile value of all gazes, reports durations that are still in line with guidelines for single glances. Results of a later real road experiment show that the gaze frequency drops in real traffic [3].

The driving behavior shows potential safety benefits in different dimensions. The total speeding time is reduced, as well as the RMS velocity of violations and the general level of illicit behavior. Similar results were found in the first simulator experiment [4], where the smart phone traffic light assistant reduced the speeding percentage of time from 60% to 25%, the speeding RMS from 12.1km/h to 6.9km/h and the number of speed violations from 6.8 to 3.6. It is interesting to note that in the first experiment no speed alert system was implemented. Thus, the main effects for speed reductions should come from the traffic light assistance and the compliant behavior of the drivers. The incorporation of a screen-filling speed alert on the phone nevertheless has the advantage that it can be easily detected and read quickly. Another benefit is that this 'nag screen' makes the system resistant to potential misuse (over speeding). It is also interesting to note that [8] reported a reduction of speeding and crashes on a real road segment after installation of a road side traffic light assistant.

VI. Conclusion

The improvements in the subjective usability ratings for a customized traffic light assistant on a smart phone are so small that the later system was not made highly adaptable for the user. The later system included items and presets that are accepted by most of the users, combined with safety-related ideas. The TDT values show a plausible order for the cognitive load of the experimental conditions. The traffic light assistant seems to impose only a minor additional demand on normal driving. And less cognitive load than a simple auditive number task. A speed alert would be accepted by many people, but with a relative high speed tolerance level. It will be a challenge for a safe real-life system to find the right trade-off. From the simulator results, there are no safety-related issues that inhibited tests of the carefully designed system on the road.

VII. Outlook

In the next stage of the KOLIBRI project, the traffic lights in the test fields were switched to a coordinated fixed time scheme (green wave). This was used to test the traffic light assistance on the road. The switching times were pre-determined. Thus, a prototype on a smart phone for experiments could be set up in order to test TDT, gaze behavior and driving in subject tests under real conditions.

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