Subliminal Visual Information to Enhance Driver Awareness and Induce Behavior Change

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ABSTRACT

Steering a vehicle has become a challenging task and this is underpinned by the fact that more than ninety percent of vehicle accidents are caused by driver errors. Cautionary, not the classical driving errors lead to this number, but accidents caused by distracted drivers reaching or exceeding their cognitive limits. To address this problem, i. e., to mitigate driving problems caused by excessive information, we propose to induce a non-conscious behavioral change in drivers by employing subliminal techniques. Within a driving simulator study we have demonstrated the feasibility of the approach to support drivers with added information without dissipating available attention resources. In a Lane Change Task (LCT) similar to ISO 26022-2010 we exposed drivers to sequences of briefly flashed visual stimuli (subliminally flashed lane change requests) to change their steering behavior. The results of the study, while mainly not statistically significant, still give support to our hypotheses that there are positive differences between control group (no subliminal messages or negative primes) and test group (exposed to positive subliminal cues). More research and experimentation is needed to improve on the perception of information priming, but we are confident that subliminally driven interfaces will find their way as additional information provider into the cars of the future.

Author Keywords

Driver-vehicle interaction; Driver errors; Human factors; Cognitive limits; Subliminal techniques; Lane Change Task; ISO 26022; NASA TLX.

ACM Classification Keywords

Human-centered computing: Human computer interaction (HCI): HCI design and evaluation methods, User studies; Human-centered computing: Human computer interaction (HCI): HCI theory, concepts and models

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DRIVER'S COGNITIVE CAPACITY: VALUABLE BUT TIGHT

Driving performance suffers from countless sources of distraction causing unpredictable driving behavior and cognitive overload. One example is the exceptionally high number of rear-end collisions caused by inattention – it has been estimated that more than 60% of rear-end collisions are caused by inattentive drivers [13]. To integrate additional warning mechanisms to compensate for the lack of perceived risk and to point the driver to the danger of too short headways is the immediate logical consequence. Scott and Gray [17], for example, reported that (visual or tactile) warning signals are an effective means to reduce traffic accidents. But on the other hand, too many warnings for specific issues stress the mental capabilities of drivers, leading finally to cognitive overload. Furthermore there is evidence that repeating warnings too often degrades their effect. Nevertheless, all currently available driving assistance systems to mitigate driving mistakes do not account for these problems, necessitating to think about new solutions to make driving more safe.

A highly controversial approach could be the application of subliminal techniques – which would not only keep the cognitive load of the driver on a low level by "hiding" the warning messages (i. e., does not stall his/her cognitive resources), but could also keep the messages in a *preconscious* state. According to S. Freud, this means that they are temporarily buffered in a "nonconscious store", and thus not consciously accessible, but faster recalled (consciously perceived) whenever necessary. The idea followed in this work is, to provide information in an inattentive or *subliminal* way to the driver. This should allow the driver to keep track on upcoming, maybe unexpected, events and to handle them adequately as his/her decision-making ability will not be impaired by high mental stress.

Can subliminal priming solve the problem?

In perception psychology, several studies on subliminal priming (c. f., cues as a hint shown in advance to the target) with highly divergent results were presented in the past, and this is actually the main reason why a lot of researchers have reasonable doubts about its practical application. Elsner et al. [6] conducted a series of experiments that used novel primes and showed that they have an effect but only if they are attended. The experiment used a classification of numerals task in which the novelty of the primes was produced by rotating or inverting the primes. Findings indicated that novel primes could only make a significant difference via the congruency effect if their representation is expected. Another factor that influences the effectiveness of primes is the temporal component of priming trials. As reported by Naccache et al. [15], unconscious priming depends on temporal attention during the presentation of a prime-target pair. The study used a numeral classification task in which the temporal attention was controlled by manipulating the predictability of prime-target pairs. Either the Stimulus Onset Asynchrony (SOA) time was varied, as proposed, for example, by [5], or the occurrence of the prime-target pair within a stream of masks was changed. In all cases, response-congruity priming [6] and physical repetition priming vanished when the temporal attention was not directed to the prime-target pair time window. The two studies match with the taxonomy proposed by Dahaene et al. [4] in which unattended subliminal stimuli have little to no priming capabilities in contrast to the attended subliminal stimuli.

Towards a more practical application, Muscarella et al. [14] conducted an experiment using high frequent brand logos as primes. The goal of the study was to assess short and long-term effects of real-life stimuli. Therefore a lexical decision task on target letter strings with brand logos was used in two experiments. The presented primes were brand logos followed by related or unrelated strings (e. g., brand names). Results suggest that high frequent brand logos can prime related strings even if 5 seconds have passed between their presentation. (For the driving context, this time period would be in the range of two seconds, the maximum delay or response time that is considered safe.) Furthermore, it gives valuable insight on how to embed arbitrary subliminal cues to observe robust long-term effects of unconscious information.

Obviously, not every prime is practical usable as they may lack any specific background context. For example, the logo of McDonald's may build up a stronger context compared to a plain arrow indicating a simple choice (e. g., a turn left/right indication or gear changing recommendation). Both primes may be well known to one, but the arrow might be too generic to invoke strong effects (reaction). This makes clear that the primes (i. e., visual stimuli) must be designed with the aim to induce strong effects, and might also explain why that many divergent results in long term priming experiments were presented in previous studies.

Research approach

Based on the taxonomy of non-conscious perception and in accordance with the recommendations of related studies, the here reported research focuses on the visual channel to deliver subliminal information to the driver. The visual modality has the highest capacity for information delivery, and since driving is essentially a visual task [3], our expectation is high that subliminally provided visual information (e. g., messages flashed so briefly that they cannot be perceived consciously) using overlays in the Head-Up-Display (HUD) or the front windshield can actually extend on this capacity. Further support for the use of visual subliminal stimuli is given by the fact that numerous technologies are now in place to facilitate the projection of information into the driver's field of view.

Research hypotheses

Picking up on the potential of subliminal techniques, previously shown for example with tactile stimuli [16], the goal of this work was to assess whether or not visual positive subliminal cues can exhibit effects on the steering behavior of drivers compared to a baseline group (no or negative primes). To demonstrate significant differences, visible and subliminally primed steering activities, e.g., Lane Change Requests (LCRs), were used to influence the driver's steering precision and response time (lane change completion time). The study was set up as a LCT [11] without a secondary task and in which visual primes were presented in a masked priming paradigm [10] to test the *response-congruency effect* [6]. We assume, that the response to a lane change request is faster for clearly visible targets if they are preceded by unconscious positive primes (test group) in contrast to trials where targets are preceded by negative primes or no primes at all (control group). With this underlying setting, our research hypotheses compile as follows

- **H1:** The steering precision of a driver, measured as deviation from the optimal track in LCT, can be enhanced through visual subliminal cues (without increasing subjective workload),

- **H2:** Drivers of the test group (with a visual positive prime presented) respond faster to lane change requests compared to control-group drivers (negative priming/no priming).

The aim of the study presented below was to condition drivers to change their driving behavior automatically based on hidden indications or cues. Experimental results should help to better understand by which extent (if at all) visual subliminal techniques can help to increase driving precision/performance or reduce cognitive workload while operating the vehicle.

Outline

The rest of the paper is structured as follows. Section 2 describes the experimental setting, method, and defines the stimuli as used throughout the study. Results of the driving experiment as well as the subjective workload analysis are presented in Section 3. The final Section 4 concludes the paper with a summary of findings and open issues.

EXPERIMENTAL SETTING

Driving simulator studies in combination with subjective analysis tools like NASA TLX are a relatively cheap, safe yet effective means to assess objective differences in interaction performance as well as subjective differences in the perception of In-Vehicle Information Systems (IVIS) or Advanced Driver Assistance Systems (ADAS) [8].

Toolkit

In this work, we are using a low-fidelity driving simulator based on OpenDS v1.0 (`http://www.opends.eu/`) to perform lane change tasks [11] in within- and between-subjects configurations. OpenDS is a Java-based open source project capable of testing various driving situations that are pre-configured via configuration files. It has a built-in measurement engine that can be configured to trigger specific measurements (e. g., reaction time), checking the validity of measures, and finally storing data of interest in CSV-type log files. In addition, it automatically records the movement data of the vehicle in a driving experiment (timestamp, x- and y-position, etc.). OpenDS comes with several integrated experimental courses that can be adapted and modified (e. g., to comply with ISO 26022). Last but not least is it also possible to extend the simulator with own components or functionality. For this work, we have implemented a module named "Priming unit" encapsulating (and adding) all the priming-relating functionality. The extension was hooked up into the drawing cycle using a so-called application state (a feature of the "jMonkeyEngine", `http://jmonkeyengine.org/`, on which OpenDS is based on), synchronizing the entire drawing cycle with the priming stimuli used in this study.

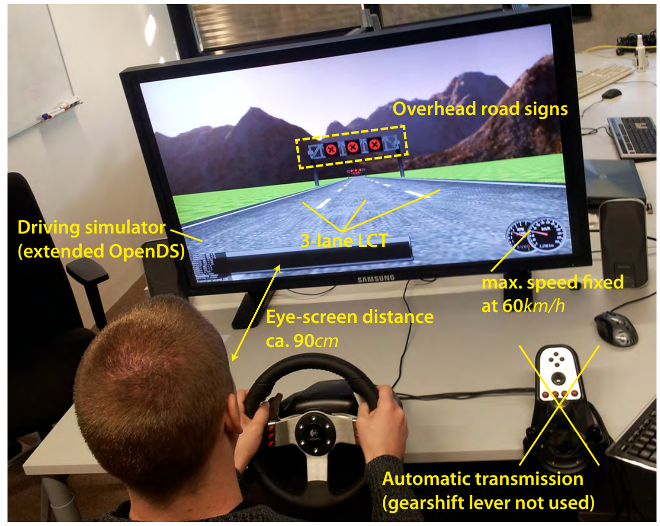


Figure 1: Driving simulator experiment (lane change task) to assess the response-congruency effect.

Method

In the priming experiment, the response-congruency effect [6] was tested. The underlying assumption was, that response to a lane change request is faster for clearly visible targets if they are preceded by unconscious positive primes (test group; Figures 4c, 4d) in contrast to trials where negative primes are assigned to either congruent or incongruent targets (control group; Figures 4a, 4b). The setting 'positive primes–no primes', assumed to result in greater differences, was not investigated in this work in favor of similar amounts of information transferred to the different groups to allow for comparative (workload) analysis.

Differences should be detectable in driving statistics (average lane deviation, mean time to complete a lane change request). Our hypothesis was that, overall, drivers of the test group (positive visual primes) would change lanes earlier and drive more close to the optimum track than control-group drivers.

Participants

For the experiment, subjects with no previous knowledge of the aim of the study were recruited from the campus of the University of Linz. To minimize possible effects of age or gender differences, only male students aged 18 to 30 years were enrolled. In total, 20 people (10 Test Group (TG), mean age 25.50, $SD \pm 2.85$, range 23–30 years; 10 Control Group (CG), mean age 24.63, $SD \pm 3.74$, range 19–32 years) participated in the study. While not of immediate effect for the study, all the subjects were in possession of a driving license for at least one year and had some experience in driving a car. The assignment to control group and test group was randomized. The pre-test inquiry revealed that none of the participants was mentally or physically handicapped except of a corrected debility of sight (8 subjects).

Apparatus and procedure

The experiment took place in a silent lab room where the experimenter welcomed one participant at a time. After being briefed in written and verbal form, and accepting the terms of participation, each participant was asked to sit comfortably by adjusting the car seat (office chair) accordingly (Figure 1). A Logitech G27 steering wheel was used by the subject to control the driving simulator and the driving scene was shown on a Samsung SyncMaster DXN 460-2 46-inch monitor (1366×768, 700cd/m^2, 5000:1 contrast, 178/178 degree vertical/horizontal viewing angle, 8ms response time) at a refresh rate of 60*Hz*. The average distance between the screen and the driver's eyes was measured at approximately 90*cm*. As the studies were conducted during the day, the room was shaded to allow a high viewing contrast on the driving scene and to avoid irritation from glaring sunlight. The driving study was based on the LCT integrated into OpenDS v1.0 (software installed on a Windows7 machine) and extended with the "Priming unit" as described in subsection 'Toolkit'. The simulation software controlled all the visual (visible and subliminal) stimuli and was responsible for all data recording. Auditory feedback on the driving scene (driving noise as provided by the simulation software OpenDS) was delivered to the driver via a set of standard stereo computer speakers (Sony SRS-A205, no sub-woofer). To allow for a later ground truth analysis, all the simulation runs were recorded by a GoPro HERO3 camera (`http://gopro.com/cameras`, 120 degree aperture angle) facing the driver's face and screen content simultaneously.

Study subjects were asked to control a vehicle in a driving simulator on a straight three lane road. The task (similar for both groups) was to react as fast and accurate as possible on upcoming lane change requests while maintaining a system-limited constant driving speed of 60 km/h=16.67m/s (according to ISO 26022-2010). This corresponds to a completion time of about 7 minutes for the course. LCRs were shown on overhead road signs as indicated in Figure 2.

The course was a slightly modified LCT as defined in ISO 26022 (2010 version) with an overall length of 8,200*m*. A total of 46 overhead signs (Figure 1) guided the driver through

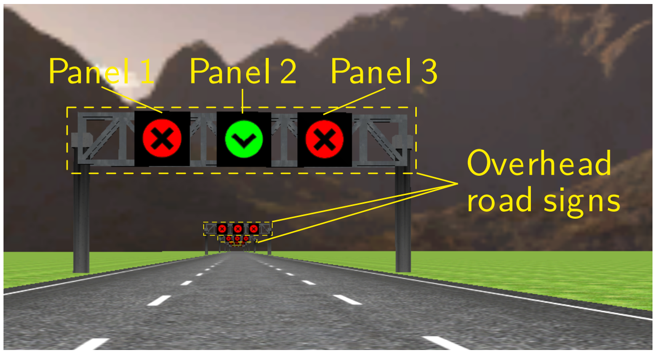


Figure 2: Lane change requests shown on overhead signs. The 'check mark' (panel 2) corresponds to the lane in which the driver is supposed to steer to.

the course, and each trial started with a warm-up phase (4 signs respectively LCRs) to acclimatize the driver with the task (no measures taken). For the remaining 42 signs, data recording (time, steering behavior, vehicle position, etc.) started after a clearly visible start sign and subjects had to complete 40 LCRs, equally distributed along the track (distance of $180m$ between two overhead signs). The last (42nd) sign indicated the end of recording and driving experiment. The 40 lane changes were grouped into three blocks, baseline 1 ("b1"-block, 10 LCRs), priming block ("p"-block, 20 LCRs), and baseline 2 ("b2"-block, 10 LCRs) as explained in detail below. After the driving experiment, subjects were first asked to complete a NASA TLX questionnaire to rate their subjective workload, than to answer up to eight additional questions related to the visibility/perception of the priming information, and were finally debriefed and dismissed. Participants were not compensated for their effort (as already announced during recruitment).

Visible stimuli (lane change requests)

The overhead signs were continuously shown to the driver, displaying a clearly visible "($\times$) ($\times$) ($\times$)" pattern on a red ground while far away from the sign, and changing to a specified lane change request pattern when coming closer to the sign (e. g., "($\times$) ($\vee$) ($\times$)" pattern; 'check mark' on green ground "($\vee$)" corresponds to the lane in which the driver is supposed to steer to), as illustrated by Figure 2. Visible patterns were displayed in the same way for all three blocks ("b1", "p", "b2") and both groups (control group, test group). The fact that drivers noticed the overhead signs and the patterns shown on them, is enough to assert that the drivers in both groups consciously perceived this information (i. e., the stimulus carried enough strength and obviously had attention: a driver would have been able to respond immediately when asked to which lane he was requested to change – and has done so in the experiment).

Subliminal cues

Regarding to the subliminal information presentation (visual attended, c. f., [4]), the composition of each of the 40 (+4) lane changes was similar and contained three stimuli (phases) as outlined in Figure 3. The information related to priming (forward mask, prime, blank mask, backward mask, blank mask; see Figure 4) was shown only very briefly – in accordance with the monitor's refresh rate of $60Hz$, each block was visible for just $16.67ms$ unless otherwise noted (no external check performed). This corresponds to an interval between the onset of the prime and the onset of the target (=SOA, [14]) of $333.33ms$, constant for the entire experiment and for all the subjects from both, test and control group. For this case, we can state that all drivers consciously perceived the visible target, but not the subliminally added information (irrespective of the content), i. e., when asked what information could be read off the screen or HUD, a test group driver would (or should) never indicate the briefly flashed preview of the lane-change request information – and this assumption is actually confirmed by the qualitative analysis of the study (see below). The control group drivers received "negative primes" all the time (i. e., for all lane changes in the 3 blocks), either with a negative (congruent) or positive (incongruent) target; Figures 4a/4b. The term "negative prime" means, that the briefly flashed invisible stimulus was always equal to the visible stimulus currently shown on the panel (negative prime corresponds to a "($\times$)" all the time). On the other hand, test group drivers were provided with a preview of the lane to change to. This means, a pattern similar to the one shown in Figure 4d was used as "positive prime" on the sign indicating the lane to change to and the pattern in Figure 4a was used on the other two direction signs.

In more details, the 44 overhead signs (4 warm-up phase, 40 testing phase) have to be looked at panel or lane granularity (3 panels per overhead sign). Each of these panels were initially set to a visible "($\times$)" pattern (see also Figure 2). The subliminal/priming stimuli were triggered three times, $80m$ (stimulus 1), $60m$ (stimulus 2), and $40m$ (stimulus 3) before an overhead sign, where the last stimulus finally led to a quasi-randomized permanent change of the indication panels (two "($\times$)", one "($\vee$)" per overhead sign), i. e., a clearly visible LCR. Two different situations where differentiated in the experiment, test scenario and control scenario.

- The **control scenario** ("b1"- and "b2"-blocks for CG and TG, "p"-block for CG) used (negative) prime sequences as shown in Figures 4a, 4b. Each of the three panels of an overhead sign presented the sequence given by Figure 4a as the car triggered stimulus 1 and stimulus 2 (negative prime, negative target, congruent). Stimulus 3 presented the sequence illustrated by Figure 4a for the non-target lane and Figure 4b for the target lane (negative prime, positive target, incongruent).

- The **test scenario** ("p"-block for TG) used prime sequences as indicated by Figures 4a, 4c, and 4d. Stimuli 1, 2, and 3 for the non-target lanes presented the sequence given by Figure 4a (negative prime, negative target, congruent). For the target lane, stimuli 1 and 2 showed the sequence as given by Figure 4c (positive prime, negative target, incongruent), thus priming the upcoming target lane information twice before visible shown (this corresponds to a "subliminal preview"). Stimulus 3 on the target lane finally used the last sequence of Figure 4 (positive prime, positive target, congruent).

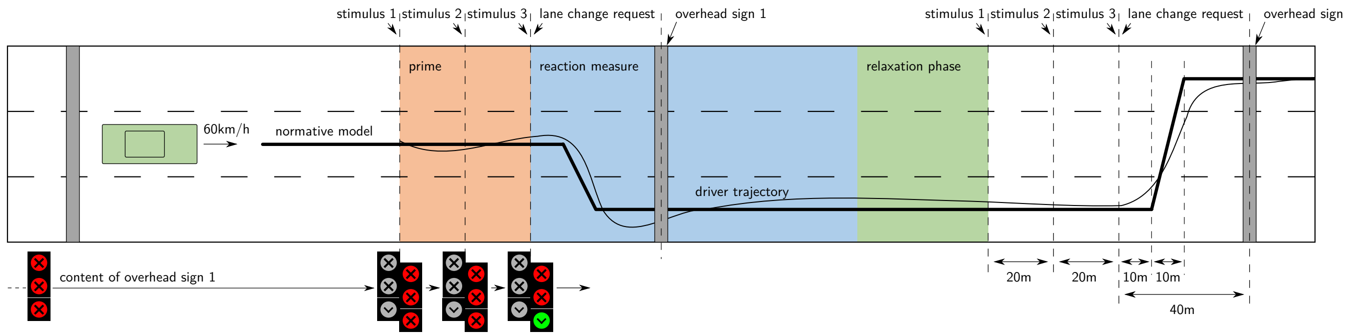
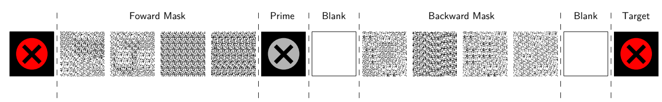


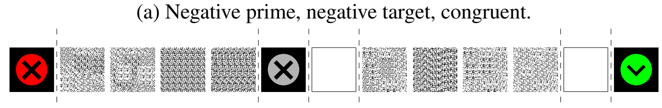
Figure 3: The bold face line is the optimal track (normative model) used as reference, and movement trajectories of subjects (thin black line) are compared against it to estimate steering precision. The colored overhead signs refer to the clearly visible stimuli (same for test, control group), the gray panels refer to the positive (test group)/negative (control group) primes.

Primes were preceded and succeeded by a forward and backward mask containing 8 random dot patterns and each sequence had a constant SOA time of $333.33ms$. The entire subliminal sequence (forward and backward masks, blanks) were shown in levels of gray to avoid interference caused by explicit color coding. The prime visibility was assessed through operationalization of the primes and a subjective questionnaire.

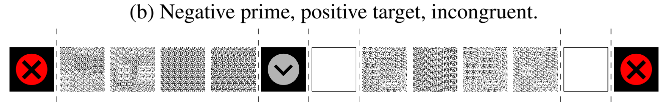
This setting and the differentiation between “negative prime” and “positive prime” might be criticized, as one can state that the control group drivers also received sort of “hidden primes”, but without any added information. We decided for this setting to have exactly the same visible and invisible information provided to the drivers, which should allow for comparative analysis of, in particular, the (subjective) workload.



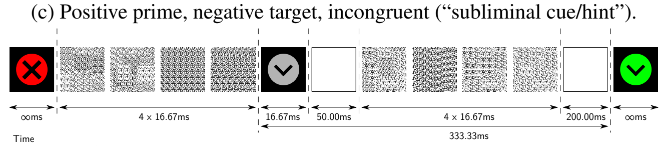
(a) Negative prime, negative target, congruent.



(b) Negative prime, positive target, incongruent.



(c) Positive prime, negative target, incongruent (“subliminal cue/hint”).



(d) Positive prime, positive target, congruent (“subliminal cue/hint”).

Figure 4: The four possible prime sequences used for stimuli 1, 2, and 3. (a) was used for stimuli 1, 2 and 3 for non-target lanes in the test and control scenario and as stimuli 1 and 2 for the target lane in the control scenario. (b) was used as stimulus 3 in the control scenario. (c) was used as stimuli 1 and 2 on the target lane in the test scenario. (d) was used as stimulus 3 on the target lane in the test scenario.

RESULTS AND DISCUSSION

Overall, three data series were recorded during the driving experiment for each subject, 1) a vehicle’s continuous positional data (i. e., trajectories to allow a mean deviation analysis between the normative model and the actual vehicle; Figure 3), 2) the lane change durations for the 40 LCRs (i. e., the time between the start of a lane change and its completion), and 3) the subjective workload score (analysis of NASA TLX [7] and additional questions to assess subjective differences between primed and unprimed conditions).

Steering precision and RT analysis

To assess the steering precision of a subject or group (MDEV, according to ISO 26022-2010), the recorded vehicle movement trajectories were confronted with the optimal track from the normative model, and the standard mean deviation was calculated and used for further assessment. In total, 8,322 samples along the 8,200m long course were recorded/evaluated (average precision of 0.98m). All the samples were interpolated and normalized to a 7,300m long series excluding the initial warm-up phase. Regarding steering on the optimal track, the vehicle in the normative model starts the lane change after a response time of 10m (or 600ms), 30m ahead the sign, and completes it after 10m as illustrated in Figure 3. This lane change behavior is similar, irrespective if the lane needs to be changed to an adjacent lane or from one outer to the outer lane via the middle lane (e. g., from left to right lane), and is supported by empirical observations who have found that drivers make a more pronounced lane change if they have to cross over a lane, thus resulting in the same avg. duration [12].

The 20m distance needed by the normative model to complete a lane change was further used as reference for the response time analysis (given the fixed driving speed of 60km/h, 20m corresponds to a lane change completion time of 1.2$sec.$). For the vehicles driven in the simulator study, the lane change completion time (or duration) was measured from the (visible) occurrence of the green check mark panel on the overhead sign (activated $40m$ ahead of the sign) and stopped as soon as the car continuously drove $1.2sec.$ on the target lane or at the latest after $100m$. These parameters were experimentally determined and allowed, while not directly comparable to response times in the reference track, a reliable detection of all lane changes in the tests. In total, 800 lane changes (20 subjects, 40 LCRs each) were measured, whereof 200 were primed ("p"-block, TG only). 22 invalid lane changes had to be discarded from the analysis (19 TG, 3 CG).

Steering precision and lane change completion times were analyzed within-subject and between-subject as follows (corresponding box plots shown in Figures 5, 6):

1. **Overall** steering precision and lane change completion time of individual subjects (between-subject): Test Group (TG) vs. Control Group (CG),
2. **Baseline** of steering precision and lane change completion time. Every subjects "B"-block[1] compared between-subject: TG_B to CG_B,
3. **Effect of "positive primes" compared to the "negative prime" condition** for steering precision and lane change completion time. Between-subject comparison of "p"-blocks, i. e., TG_p to CG_p,
4. **Effect of priming** in a within-subject comparison of test group subjects, i. e., "p"-block (TG_p) compared to "B"-block[1] (TG_B),
5. Assessment of a **learning effect** by comparing steering precision and lane change completion times in "b2"-blocks to same measures for the "b1"-block. Within-subject analysis for both groups, TG_{b2} to TG_{b1}, CG_{b2} to CG_{b1}.

In the following, only the most relevant findings are presented and discussed.

Steering precision

A Shapiro-Wilk test verified that the "B"-block followed a normal distribution for both, control and test group: $TG_B : W = .966, p = .851$ and $CG_B : W = .933, p = .484$ at a .05 significance level. One-way ANOVA revealed that the means of steering precision for TG ($M_t = 1.02m$) and CG ($M_c = .878m$) were not significantly different: $F(1, 18) = 5.77, p = .129$. The performance of the groups was balanced by $\Delta M_{t,c} = .147m$ to make the series comparable. F-tests confirmed that each test case was of equal variance, thus a left-tailed t-test with a significance level of .05 could be used to test whether or not the steering precision of the TG was indeed better than the CG as hypothesized in (**H1**) (i. e., corresponding to a smaller avg. deviation from the optimal track for the TG compared to CG).

Evaluation results shown in Table 1 clearly reveal that there is no significant difference between TG and CG in the overall performance (first row). Furthermore, there is no significant difference between the priming block of the two groups (3rd row). A significant lower deviation was reached in the within-subject comparison of priming ("p") and baseline ("B") blocks for both groups (4th and 5th row). A learning effect, evident as improved steering precision (i. e., lower deviation) of "b2"- compared to "b1"-blocks, could be detected for CG (7th row) but not for TG (6th row).

[1]Please note that in the following a "B"-block refers to the unification of both, the corresponding "b1"- and "b2"-blocks.

Table 1: Results of the steering precision analysis (deviation from optimal track; t-test, left-tailed).

H_0	t	df	p-value	std	95% CI
TG $\geq$ CG	.174	18	.431	.178	.124
$TG_B \geq CG_B$	1.07	18	.5	.207	.160
$TG_p \geq CG_p$	.412	18	.342	.160	.094
$TG_p \geq TG_B$	7.11	9	$2.78 \cdot 10^{-5}$	.086	.144
$CG_p \geq CG_B$	6.99	9	$3.18 \cdot 10^{-5}$	.074	.121
$TG_{b2} \geq TG_{b1}$	1.27	9	.117	.269	.047
$CG_{b2} \geq CG_{b1}$	3.13	9	.006	.144	.059

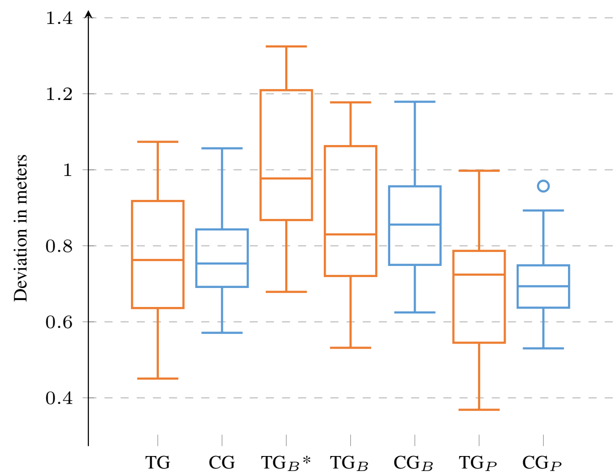


Figure 5: Box plots of the mean deviations used in the analysis. * series not normalized.

Lane change completion times

Recorded data regarding the lane change completion time was found to follow a normal distribution ($TG : W = .943, p = .594$, $CG : W = .891, p = 175$) with average completion times for TG calculated at $M_t = 3.01 \cdot 10^3 ms$ and for CG at $M_c = 2.82 \cdot 10^3 ms$. ANOVA indicated no differences between-subject: $F(1, 18) = .592, p = .451$ where $\Delta M_{t,c} = 190.62$ms was used as normalization factor. Table 2 summarizes the results of the left-tailed t-test for each of the above described evaluation cases.

The findings in Table 2 indicate no significant difference between TG and CG, neither in the overall performance (1st row) nor in the priming block (3rd row). In contrast, there is a significant difference when comparing the baseline ("B") with the priming ("p") block within-subject (4th and 5th row). The assessment regarding a potential learning effect suggest a significant difference for CG (7th row) but not TG (6th row).

Table 2: Results of the lane change completion time analysis (t-test, left-tailed).

H_0	t	df	p-value	std	95% CI
TG $\geq$ CG	.113	18	.544	524.67	433.47
$TG_B \geq CG_B$	$1.83 \cdot 10^{-15}$	18	.5	.553.78	429.46
$TG_p \geq CG_p$	.237	18	.592	508.11	448.02
$TG_p \geq TG_B$	3.18	9	$5.6 \cdot 10^{-3}$	180.73	-76.99
$CG_p \geq CG_B$	5.93	9	$1.09 \cdot 10^{-4}$	125.55	-162.96
$TG_{b2} \geq TG_{b1}$	.855	9	.207	477.25	147.50
$CG_{b2} \geq CG_{b1}$	2.63	9	.013	336.85	-85.70

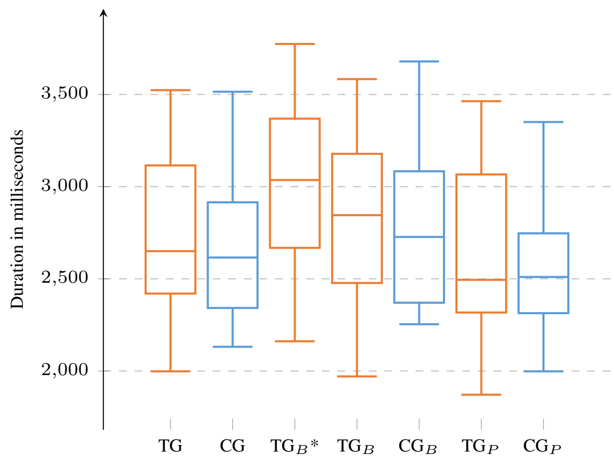


Figure 6: Box plots of the time measures used in the analysis. * series not normalized.

Subjective workload analysis

Once the simulator task was completed, the NASA TLX form was presented to subjects to evaluate the subjective workload experienced. NASA TLX requires participants to rate their perceived levels of mental, physical, and time demands associated with a task as well as their effort, performance, and frustration during that task on a 20 level Likert scale. NASA TLX has been used extensively in a variety of projects for assessing the mental workload experienced while performing lane change tests, e. g., [2], [1]. The effect of priming on the NASA TLX scores were analyzed with separate independent samples t-tests for each of the 6 items with probability level for statistical significance set to .05 (Table 3).

As for the NASA TLX, both groups perceived – as expected – similar subjective workload during the driving simulator experiment (Table 3, last row, p=.172). Only the scores on the subscales “time demands” and “frustration” showed a larger deviation, whereof the last reached a statistically significant level. A high score on “time demands” would mean that the pace of the task and the caused time pressure was (too) high while completing the task. For this study, time demands were on a quite high level and interestingly the subjects from the test group felt much more challenged than the control group, but the difference is not significant ($t(18) = -1.71, p = .104, \alpha = .05$). A high score on “frustration” would mean that the participant was strongly annoyed or discouraged while performing the task, or in other words that high stress (for whatever reason) was put on the subject by the interaction with the lane change task. For this study, test group drivers were more stressed than control group drivers. Both levels are moderate (5.50 $\pm$ 2.76 versus 8.80 $\pm$ 4.08) and the difference reached statistical significance ($t(18) = -2.11, p = .048, \alpha = .05$).

Table 3: Between-group comparison of subjective workload.

	CG		TG		
NASA TLX	Mean	SD	Mean	SD	p-value
Mental demands	5.20	4.66	6.30	4.95	0.615
Physical demands	5.60	4.27	5.70	4.52	0.960
Time demands	8.40	5.95	12.2	3.71	0.104
Performance	5.5	2.46	6.8	3.36	0.337
Efforts	7.60	4.67	7.80	4.13	0.920
Frustration	5.50	2.76	8.80	4.08	0.048
Sum workload	**6.30**	**4.13**	**7.93**	**4.12**	**0.172**

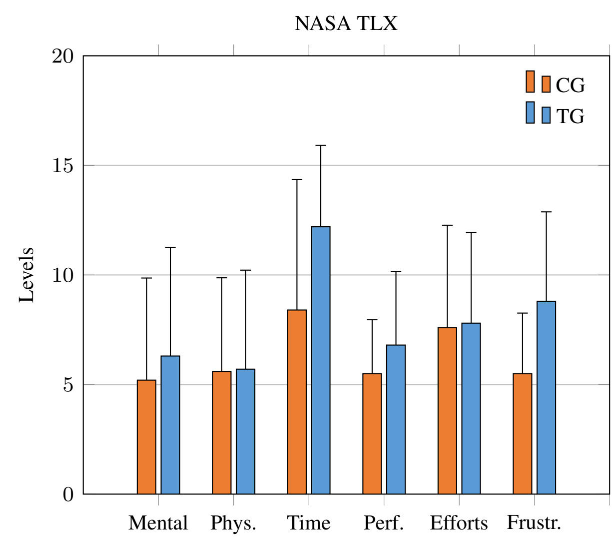


Figure 7: Subjective workload analysis including standard deviations.

Individual perception of primes

After the TLX, subjects had to answer additional questions related to the perception/visibility of the priming information. Most influencing, results from this question block (8 questions) revealed that 20% (2 out of 10) of the control group and another 20% (2 out of 10) of the test group believed that they were exposed to subliminal stimuli (Q: “Do you believe that additional information (of very short duration, i. e., ‘subliminal’) was presented during the driving task?”). For the test group, the comparison of Steering Precision (SP) and Lane Change Duration (LCD) in the “p”-block between the

20% that reported prime visibility (SP: $M = .65m$, LCD: $M = 2.37 \cdot 10^3 ms$) and the rest of the group (SP: $M = .69m$, LCD: $2.7 \cdot 10^3 ms$) revealed no significant difference (SP: $t(8) = -.88, p = .41$, LCD: $t(8) = -.74, p = .48$). Asked in more detail, not a single person had a concrete idea or could describe in detail what the subliminal stimulus was, how it was presented, or what its aim could have been (Q: "Which additional information do you think was presented in a subliminal way?"). One person noticed a blinking on the screen (caused by the switching between visible–subliminal–visible contents of the signs) and thought that this blinking might have been a teaser to direct visual attention towards the driving scene and/or the overhead signs.

No further trend regarding the perception of the primes could be detected in the questionnaire. For the question whether they felt that the response time was improved because of the additional subliminal information (Q: "Do you think that the additional subliminal information shown during the driving task led to improved reactions on your part?"), the control group answered with 8.5±9.19 (20-level Likert scale, 1 …strongly disagree, 20 …strongly agree), test group with 8±2.82. Asked about the subjective perception if the subliminal information could have led to more precise lane changes (Q: "Do you think that you changed the lane more precisely/optimal because of the additional subliminal information?"), the control group answered with 8±5.66, the test group with 4.5±2.12. Interestingly, for the last two questions the average score is higher for the control group, which were not exposed to affective/manipulative primes, than the test group. This might be another reason that the setting needs to be improved for a repeated experiment (as described before).

Discussion and outlook

Tables 1 and 2 (and corresponding Figures 5, 6) give a brief overview of the test cases and data correlation. The overall performance of the test and control group after normalization was fairly the same – this applies to the steering precision (avg. deviation from optimal track) but also to the lane change completion times. All values and value ranges were almost equal, but TG showed a higher variance in results, in particular for the steering precision (deviation). The normative model used here as comparative metric is not really realistic, but, as every subject was compared against it, qualified for a first performance assessment. In the future, it should be replaced with a better approach, e. g., by comparing every subject against their own baseline driving without any priming.

Further on, the findings could not confirm that the steering precision of a driver, measured as deviation from the optimal track, can be enhanced through (positive) visual subliminal cues (**H1**), and also not that drivers who received positive visual primes responded faster to lane change requests compared to the control-group drivers obtaining only negative primes (**H2**). There was also no statistical significant effect of the "positive primes" compared to the "negative primes" condition between the two groups ("p"-blocks), neither for steering precision nor lane change completion times.

Nevertheless, both groups had a statistically significant lower deviation (steering precision) or duration (lane change completion time) when comparing baseline blocks ("B") with the priming block ("p") in a within-subject analysis. For TG, this could be interpreted as a positive priming effect that resulted in an increased steering precision and a decreased reaction time, because no significant learning effect (avg. deviations of "b2"- vs. "b1"-blocks at $\alpha = .05$) was detected. On the contrary, CG's learning effect assessment reached significance, explaining the performance gain in the within-subject analysis.

There was no significant difference between the overall workload of both groups, indicating that the additional information the test group perceived did not increase their workload. The reason for similar workload could also, as already mentioned earlier, originate from the experimental setting with its negative and positive priming conditions and the fact that control group drivers also received primes, but without added information. Nevertheless, the level of "frustration" reached statistical significance (between-subject), which could be caused by the additional information presented in the "p"-block. Since the LCRs were presented twice beforehand, the subjects may have felt the stress or need to do something (e. g., to change the lane). As a result of this, TG was at the end of the course significantly more exhausted (frustrated) than CG.

The clearly divergent results of the between- and within-subject analysis suggests further research. Someone might argue that the low number of participants ($N = 20$) favors the within-subject findings, since generalization from a small random sample might be too error prone. On the contrary, the fairly low p-value on the learning effect assessment for the steering precision (TG, p=.117), might point to a performance gain caused by a learning effect. However, this argument is not supported by the learning effect of the lane change duration times (TG, p=.207).

A potential problem that caused these ambiguous results may have been the three panels per overhead sign, each carrying its own prime, dissipating the attention and thus reducing the overall priming effect. Another potential problem in the setting used for the actual study was that a single prime might be too weak to cause a significant effect. Jaskowski et al. [9], for example, found out that by presenting series of similar primes, speed and errors of reactions to the stimuli were remarkably affected. The authors found an accumulation of priming effects but further showed that the effect of accumulation was limited. These results suggest to repeat the here presented lane change experiment with a setting in which series of similar "positive primes" (i. e., sort of "preview" of the upcoming lane change request) are shown to test group drivers, and series of "no primes" (Figure 4a) or absolutely no primes are shown to the control group.

We would further like to expand this work to compare the effect of priming with visual hints, i. e., graphical representations of potential actions that can be taken in order to assist with the completion of a task [18] (i. e., lane change completion time). Additionally, also differences in the settings negative primes and no primes at all should be investigated in additional studies.

CONCLUSION

In order to mitigate driving problems caused by excessive information, we proposed in this work to induce a nonconscious behavioral change in drivers by employing subliminal techniques. Concretely, we exposed drivers in a driving simulator study similar to a LCT based on ISO 26022 to briefly flashed visual stimuli (lane change requests) to change their steering behavior. As confirmed by the subjective workload analysis (NASA TLX), we have demonstrated the feasibility of our approach in supporting drivers with added (visual) information without dissipating available attention resources. The quantitative results of our study do not fully confirm that there are significant differences between the control group (no subliminal messages or negative primes) and the test group (exposed to positive subliminal cues), but we have gained useful insights for the design of driver-vehicle interfaces to convey subliminal information. Finally, we believe that subliminal support through nonconscious perception is a promising approach to preventing cognitive overload in driver-vehicle (or human-machine) interaction and we are confident that subliminally driven interfaces will find their way into the cars of the future.

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