USING GLANCE BEHAVIOUR TO EVALUATE ACC DRIVER CONTROLS IN A DRIVING SIMULATOR

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This paper examines the glance behaviour of drivers while interacting with two different driver-vehicle interface concepts for an Adaptive Cruise Control (ACC) system. With the *integrated* concept, the speed and following distance controls were located on the steering wheel whereas with the *divided* concept the speed control was moved to the dashboard. A virtual Head-Up Display (HUD) was used to show the ACC settings and current speed. Twelve subjects (19 to 53 years old) drove a rural road course in a fixed-base driving simulator while being verbally instructed to adjust the speed and/or following distance of the ACC system. Dividing the controls between the steering wheel and dashboard caused significantly larger mean and maximum glance times and a lower glance frequency to the displays and controls. The percent glance time “off-road” furthermore increased significantly during task completion. Other significant results were observed between the task type and task length.

Technological development and market competition are driving the steady increase of in-vehicle information systems and Advanced Driver Assistance Systems (ADAS) available on the market. These systems aim to improve driver comfort and safety by monitoring the vehicle, surrounding traffic and environmental conditions. They adjust the vehicle’s state, give feedback to the driver or request input from the driver. However, these actions can distract the driver from the driving task itself. For example, the study by Klauer, Neale, Dingus, Ramsey, and Sudweeks (2005) showed that driver inattention was the primary factor contributing to 78% of crashes and 65% of near-crashes. Completing secondary tasks with in-vehicle systems could have a detrimental affect on vehicle performance. Therefore these systems must be implemented in such a way to support but not distract the driver.

One ADAS is the Adaptive Cruise Control (ACC) system, which is available in many luxury cars on the market. Within operational boundaries, ACC not only controls the vehicle speed (as is the case with conventional cruise control), but also controls the following distance to the vehicle ahead. While driving, drivers can set desired speed and following distance, which are potentially distracting tasks. Interaction with ACC systems must be designed very carefully in order to not lose the safety benefits that this ADAS was designed to achieve.

Therefore, we designed two different driver-vehicle controls for adjusting an ACC system. For the *divided* concept, the speed selector knob was placed on the dashboard and the following-distance slider on the left side of the steering wheel. The *integrated* concept combined both controls on the left side of the steering wheel, with a scroll wheel for the following distance surrounded by a selector ring for the speed. Instead of placing the controls on the steering column, the two concepts were designed to demonstrate the use of the steering wheel and dashboard as control locations. In addition, the ACC settings were displayed in a virtual head-up display instead of in the instrument panel. The goal of this study was not to examine driver behaviour while driving with ACC (e.g., Fancher, 1999; Rudin-Brown & Parker, 2004; Stanton & Young, 2005), but rather to examine driver distraction while adjusting ACC settings. The initial results of driver behaviour while using these ACC controls have been reported by Thompson, Tönnis, Lange, Bubb, and Klinker (2006), but the glance behaviour was not explored in detail. Therefore this paper will focus on an in-depth analysis of the driver visual behaviour while interacting with two different driver controls for an ACC system.

METHOD

Participants

Twelve drivers (6 male, 6 female) participated in the study. They were between 19 and 53 years old (M = 37, SD = 14). All held a valid driver’s license and were primarily staff or students at the Technical University of Munich (Technische Universität München). Two drivers had participated in a previous study in the driving simulator. The volunteers were paid 30 Euros for the two-hour experiment.

Apparatus

The experiment was run in a fixed-base driving simulator with a 40° field of view. Subjects drove a modified BMW E30 convertible with automatic transmission and simulated motor sounds on a two-lane rural road course. Two interchangeable, wireless steering wheel inlays housed the steering wheel controls, whereas the speed control for the *divided* concept was mounted permanently on the dashboard. The ACC settings were shown in a simulated Head-Up Display as analog symbols with a digital value (Figure 1). Each complete symbol subtended an angle of 1.5° and was located 6.45° below the horizon.

Figure 1. The driver's view of the Head-Up Display

The Dikablis helmet-mounted eye-tracking system (Lange, 2005) was used to record glance videos of the subject's right eye superimposed on the scene ahead. These videos were then manually analysed off-line (frame-by-frame) to determine the location (Area of Interest - AOI) and duration of each glance. The glances were measured according to ISO 15007-1 (ISO, 2002). Therefore the glance time included the dwell time (fixations and saccades in one AOI) and the transition time to that AOI. Seven AOIs were used for the analysis: Roadway, Traffic Sign, Other Outside, HUD, Dashboard, Steering Wheel, and Other Inside. The first three were defined as "on-road" and the last four as "off-road". Although the HUD was superimposed on the roadway, it was classified as "off-road" since it belongs to the vehicle controls and displays.

Procedure

Participants first completed a demographic questionnaire and then read a description of the two different configurations of the ACC driver controls. Once finished, the eye-tracking system was calibrated and the drivers subsequently drove one practice round with eye-tracking (12 minutes). The study used a block design where drivers were trained and completed experimental trials with one control design before moving onto the second design. The presentation order was balanced between participants based on age and gender. The first part of the training focused solely on task completion while parked. Drivers were given verbal instructions from the experimenter to change the ACC settings. Practice tasks were repeated until the tasks could be completed without errors. In the second part of the training, drivers repeated practice tasks while driving. Training continued until they could adjust both ACC controls while driving at least 80 km/h (50 mph) without any lane departures and they felt confident to continue. Therefore, in some cases, the training lasted up to 15 minutes.

For the experimental trials, the participants drove the same rural road course as in the practice trial, but were given 18 tasks at specific locations on the course. Depending on the vehicle speed, the fixed-length course was completed in 10 to 12 minutes. The task order and placement were identical for both experimental blocks and the verbal instructions were identical to the training. The experiment concluded with an interview concerning the driver's subjective opinions of the ACC driver controls and HUD.

Experimental Design

A within-subjects design was used, with all drivers using both ACC concepts. The independent factors were *concept* (divided, integrated), *task type* (speed, distance or both) and *task length* (short or long). The *short* tasks consisted of small adjustments that required only one to three clicks (e.g., five km/h or three mph faster), whereas the *long* tasks consisted of large adjustments that required five to sixteen clicks (e.g., 40 km/h or 25 mph faster). With each ACC concept, participants completed six tasks for each task type (divided equally between *short* and *long* tasks).

The dependent glance behaviour measures included mean glance duration, maximum glance duration, glance frequency, total glance time and percent glance time. These were calculated overall, task vs. no task, off-road vs. on-road and per AOI. Other dependent measures were recorded, such as task time, driving performance and subjective opinions, and are reported elsewhere (Thompson et al., 2006).

Since the dependent measures were not normally distributed (all $p < .05$ according to the Kolmogorov-Smirnov Z test), nonparametric tests were used to evaluate significance, in particular the Mann-Whitney U Test (Z values) for testing the difference between two groups and the Kruskal-Wallis H Test (χ^2 values) for three or more groups.

RESULTS

Total Glance Time

Without any tasks, drivers spent approximately 75% of the time looking at the road scene ahead (Figure 2). The glances were primarily at the roadway (64 to 66% of the total time), although looking at traffic signs accounted for 5 to 6% of the total time and looking at irrelevant objects outside the vehicle (advertising billboards, trees and hot-air balloons) accounted for 3 to 4% of the total time. Finally, drivers spent 23 to 27% of the total glance time looking at the HUD and less than 1% looking at the driver controls.

As shown in Figure 2, the glance distribution changed during task completion. On average, drivers spent as little as 42% of the time looking at the roadway and looked only 2% of the time at traffic signs; the total time of the "extra glances" decreased to as little as 0.3%. Drivers spent most of the glance time "off-road" looking at the HUD (39% to 50% of the total time). Surprisingly low, the percent glance time to the vehicle controls varied between 0.8% (adjusting the following distance with the *integrated* concept) to 3.5% (adjusting the both controls with the *integrated* concept). As hypothesized, drivers only looked at the steering wheel while using the *integrated* concept, but glanced at both the steering wheel and the dashboard while using the *divided* concept. This included

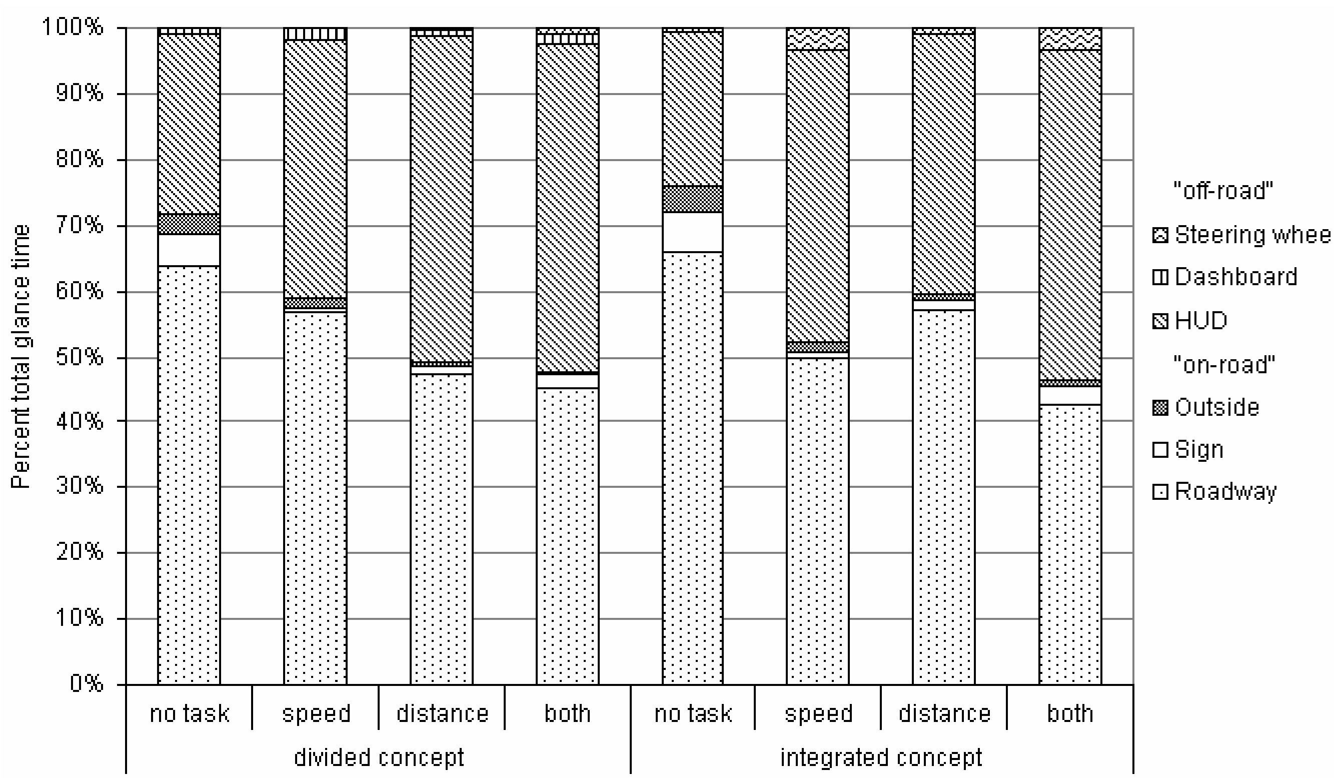

Figure 2. Distribution of total glance time between Areas of Interest for each task and concept

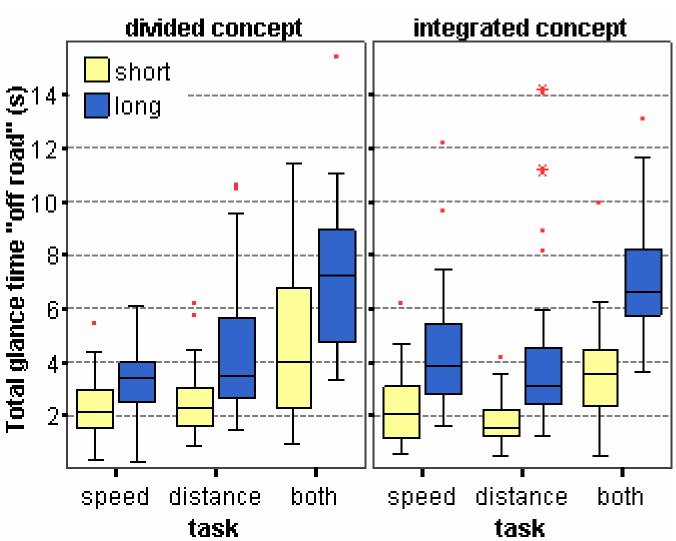

Figure 3. Total glance time “off-road” for each concept, task type and task length

looking at the dashboard for the distance control that was located on the steering wheel.

During task completion, the percent glance time “off-road” increased significantly compared to driving without tasks, Z =-16.09, p < .001. It also was significantly higher when both controls were adjusted as compared to only one control, χ^2 = 8.996, p = .011. Drivers spent more than half of the time (52 to 54%) looking “off-road” while adjusting both controls. In addition, the percent glance time “off-road” was significantly longer for the *long* tasks compared to the *short* tasks, Z = -3.228, p = .001. There was no statistical difference between ACC control concepts. However, there appears to be an interaction between task and concept for this measure. As can be seen in Figure 2, the glance time “off-road” was less for the *divided* concept during the *speed* task (41% vs. 48%) but less for the *integrated* concept during the *distance* task (41% vs. 51%).

In absolute terms, the *short distance* task combination had the shortest total glance times with means of 2.4 s for the *divided* concept and 1.7 seconds for the *integrated* concept (Figure 3). Conversely, drivers had the longest total glance times during the *long both* task combination with means of 7.2 s and 7.8 s for the *divided* and *integrated* concepts, respectively. Similar to the percent glance time measure, there was no statistical difference in total glance time between concepts. Adjusting both controls caused significantly longer total glance times than adjusting only one control, χ^2 = 94.5, p < .001. Also, the total glance time was significantly longer for *long* tasks compared to *short* tasks, Z = -9.956, p < .001.

Glance Frequency

During task completion, the number of glances “off-road” depended significantly on the type of task, χ^2 = 90.75, p < .001. There were significantly more glances “off-road” while drivers adjusted both settings as opposed to only one setting. However, there was no significant difference between the ACC concepts, though there appears to be an interaction between concept and task type. For the *speed* task, the *divided* concept had the fewest glances, but for the *distance* task the

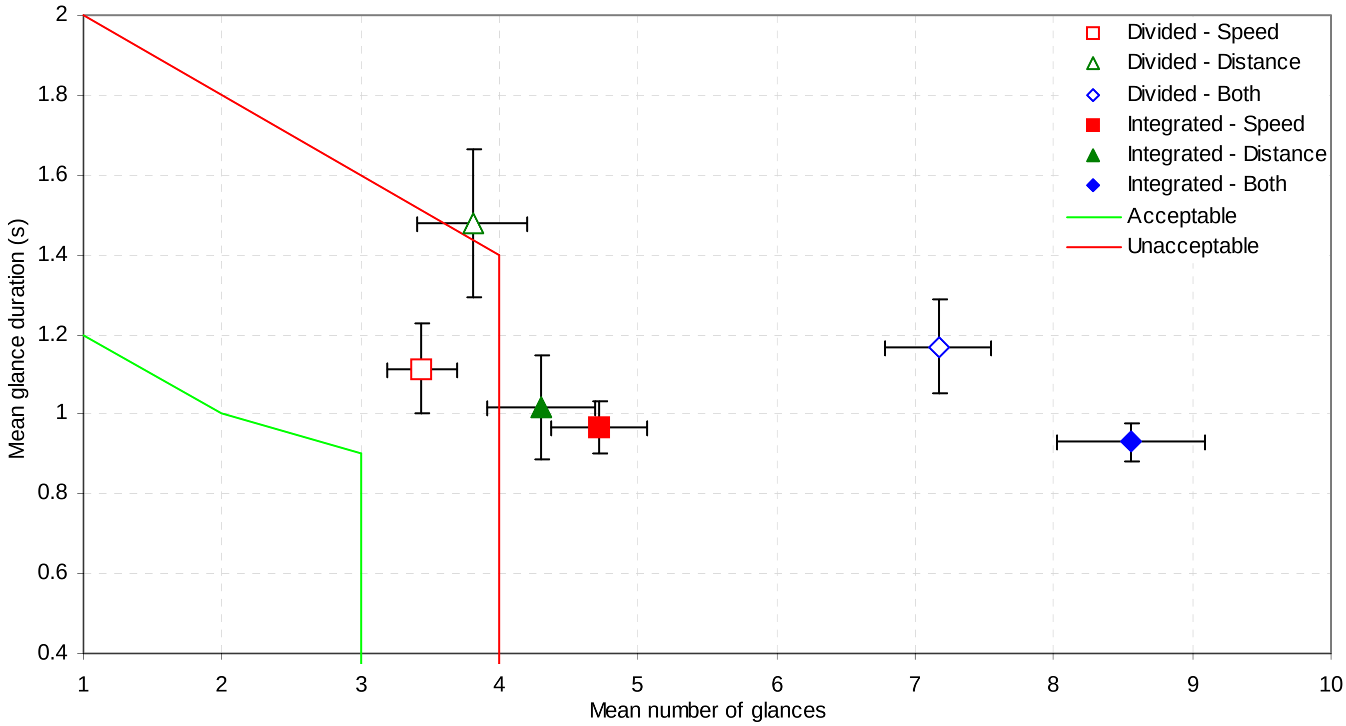

Figure 4. Mean number of glances and glance duration for *long* tasks (superimposed on the Zwahlen diagram). Error bars represent SE.

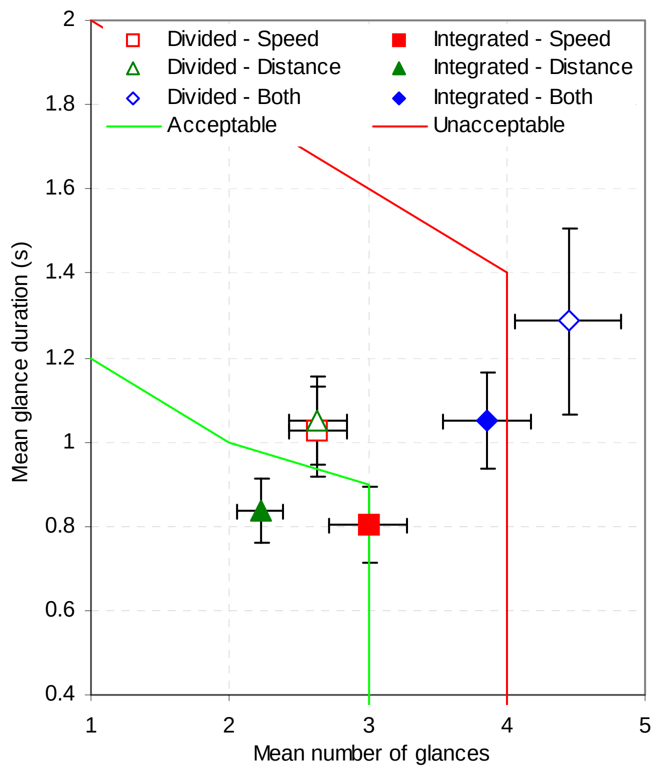

Figure 5. Mean number of glances and glance duration for *short* tasks (superimposed on the Zwahlen diagram). Error bars represent SE.

integrated concept had the fewest glances. Both concepts required a similar number of glances for the *both* (speed + distance) tasks. In addition, the number of glances during the *short* tasks was significantly lower than the number of glances during the *long* tasks, $Z = -8.967$, $p < .001$. In general there were twice as many glances for the *long* tasks compared to the *short* tasks.

In Figures 4 and 5, the mean number of glances for each task and concept is plotted against the mean glance duration for the *long* and *short* tasks, respectively. The design guidelines proposed by Zwahlen, Adams Jr., and DeBald (1988) are also shown for reference. The number of glances for the *short* tasks generally falls within the recommended four glances, but the number of glances required for the *long* tasks does not. The most glances were observed during the *long both* task combination with the *integrated* concept; the number of glances ranged from 4 to 19 with a median of 8. With the *divided* concept, drivers required 3 to 12 glances with a median of 7.5 for this task.

Glance Durations

The individual glance durations varied greatly between subjects. One driver had very short glances "off-road", whereas others sometimes had very long single glance durations. In particular, five of twelve drivers had median values with the *divided* concept that were above the 2.0 second recommendation for single glance durations (Alliance of Automobile Manufacturers, 2003), whereas all median values with the *integrated* concept were less than 1.7 seconds.

Without any tasks, drivers glanced at the HUD to check vehicle speed. The average glance duration to the HUD was 0.65 s (*SD* = 0.34) with the *divided* concept and 0.57 s (*SD* = 0.19) with the *integrated* concept. During task completion, there was a significant increase in the single glance durations to the HUD and a significant decrease in the glance durations to the roadway, traffic signs and other outside objects (all $p < .01$). When combined together, this led to a significant increase in the average glance duration "off-road" ($Z = -14.212$, $p < .001$). The mean and maximum glance durations to all the "off-road" AOIs were significantly shorter with the *integrated* concept than with the *divided* concept (all $p < .01$).

The mean glance durations "off-road" are portrayed along with the number of glances in Figures 4 and 5. For example, the average glance duration to the HUD was 0.94 seconds (*SD* = 0.56) for the *integrated* concept compared to 1.22 seconds (*SD* = 0.91) for the *divided* concept. In addition, the longest glance duration "off-road" was 8.0 s with the *divided* concept compared to 6.2 s with the *integrated* concept. Contrary to other glance measures, the type of task did not have a significant influence on the average glance durations, but rather only on the maximum glance durations; the *both* (speed + distance) task had significantly higher maximum glance durations, $\chi^2 = 19.697$, $p < .001$. However, the task length did have an effect on the glance durations, with longer tasks having larger mean and maximum glance durations to the HUD, $Z = -2.186$, $p < .001$ and $Z = -4.367$, $p < .001$.

DISCUSSION

Although ACC is designed to support the primary task of driving, adjusting the settings of the ACC system is in itself a secondary task that should not distract the driver. Therefore, glance behaviour was used as a measure of driver distraction to compare two ACC driver control concepts. These two concepts differed in control location (steering wheel vs. dashboard) and used a head-up display to provide feedback on the ACC settings and current speed. Using glance behaviour, the findings of this study support previous recommendations for the design of driver controls and in-vehicle information systems.

Firstly, dividing the controls between the steering wheel and dashboard caused longer mean and maximum glance times and a lower glance frequency to the displays and controls. It appears that the separated control location also confused some drivers, since there were glances to the dashboard during *distance* tasks where the control was located on the steering wheel. Thus, the controls for an ACC system should be kept together, preferably on the steering wheel. This supports the UMTRI Guideline 3.2: "controls used most frequently or for critical functions should be close to the predominate position of the hands" (Green, Levison, Paelke, & Serafin, 1994).

Secondly, most drivers looked longer at the speed control for the *integrated* concept compared to the *divided* concept (in particular for *long* tasks). During the post-trial interview, many participants mentioned that it was difficult to operate a rotating disk on the steering wheel. The frame of reference of the control rotates with the steering wheel and so they had to look at the control instead of being able to feel the location of the control. Therefore, caution is advised when using rotational controls on the steering wheel.

Thirdly, the mean and total glance durations to the HUD were longer while using the following distance slider (*divided* concept) compared to the scroll wheel with click stops (*integrated* concept). Since click stops facilitate shorter glances, it is recommended that ACC controls provide this form of haptic feedback.

Finally, the type of task affects glance behaviour. Adjusting the desired following distance proved to be the least visually demanding task and adjusting both settings was the most demanding. Small adjustments to the driver controls were also less visually demanding than large adjustments. Therefore, ACC controls should be designed so that drivers need only make a few adjustments to one control at a time.

Future research could investigate how ACC driver controls can be integrated with other controls for in-vehicle information, driver assistance and collision warning systems.

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