

# Effect of active cruise control design on glance behaviour and driving performance

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## Abstract

Minimising driver distraction is a crucial factor in the design of new driver assistance systems and in-vehicle information systems. Therefore two different driver-vehicle interface concepts for an Active Cruise Control (ACC) system were designed and tested with 12 drivers in a static driving simulator. These concepts differed in the location (steering wheel vs. dashboard) and type of controls. Feedback on the ACC settings was given in a simulated Head-Up Display. While driving, participants were required to adjust the desired speed and following distance of the ACC system. The concepts were compared based on objective measurements of task times, driving performance and glance behaviour as well as subjective questionnaires. The type of task had a significant effect on all dependent measures, whereas the control concept had a lesser effect. The results are used to derive guidelines for the general design of the driver-vehicle interface of such driver assistance systems.

*Key words:* vehicle ergonomics, driver distraction, active cruise control (ACC), advanced driver assistance systems

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## 1. Introduction

Technological development and market competition are driving the steady increase of in-vehicle information systems and advanced driver assistance systems available on the market. On the other hand, driver inattention is the primary factor leading to collisions, contributing to 78% of crashes and 65% of near-crashes [1]. Completing secondary tasks with such in-vehicle systems can have a detrimental affect on vehicle performance [2]. Therefore these systems must be implemented in such a way to support but not distract the driver in the primary task of driving. One such system is Adaptive or Active Cruise Control (ACC), which is available in many luxury cars on the market. This advanced driver assistance system was designed

to increase safety and driver comfort. 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. Previous ACC studies have concentrated on behavioural adaptation while driving with ACC [3,4], but did not specifically address the task of adjusting the ACC settings. Therefore this aim of this study was to investigate the extent of driver distraction while interacting with an ACC system. Two different driver-vehicle control concepts were designed to explore the effects on task performance, driving performance and visual distraction. These concepts differed in the location of the controls (steering wheel vs. dashboard) and the degree of haptic feedback (with or without click stops). The following sections describe the two ACC

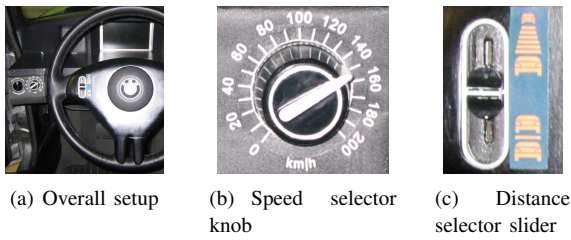


Figure 1. Driver controls for the divided concept

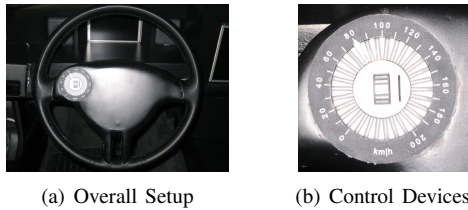


Figure 2. Driver controls for the integrated concept

driver-vehicle interface concepts and the experimental method used to evaluate the two designs. The results are then used to derive recommendations for design.

## 2. Concepts

### 2.1. Driver controls

Two different ACC control concepts were developed and implemented in a static driving simulator. These were named the *divided* and *integrated* concepts. Both of these concepts were used to set the desired speed and the desired following distance of the ACC system. For the *divided concept*, a speed selector knob was located on the dashboard to the left of the steering wheel and a following-distance slider was located on the left side of the steering wheel (Figure 1). For the *integrated concept* both controls were combined on the left side of the steering wheel, with a barrel key for the following distance surrounded by a selector ring for the speed (Figure 2). All controls (except for the following distance slider from the divided concept) were implemented with click stops in increments of 5 km/h respectively 0.1 sec. The desired speed could be set between 30 to 200 km/h and the following distance between 0.9 and 2.0 seconds.



Figure 3. Visualisation of the HUD

### 2.2. Visual feedback in the HUD

Visual feedback about the ACC settings was given in a Head-Up Display (Figure 3) as analog symbols with a digital value. Each complete symbol subtended an angle of  $1.5^\circ$  and was located  $6.45^\circ$  below the horizon. In the HUD, the desired speed was shown to the left of the current speed and the desired following distance to the right.

The symbols were designed in conjunction with the driver controls in order to maintain primary control-display compatibility [5]. In order to increase the desired speed, the driver control was rotated to the right. Correspondingly, the orange triangle also moved to the right around the speedometer icon (Figure 4(a)). In order to increase the following distance, the driver control was pushed upwards. Correspondingly, the number of bars in the symbol increased and the upper car moved further away (Figure 4(b)).

## 3. Method

### 3.1. Participants

Twelve drivers (6 male, 6 female) participated in the study. They were between 19 and 53 years old (mean = 37, s.d. = 14). All participants held a valid drivers license and were primarily staff or students at the Technische Universität München. Two subjects had participated in experiments in the driving simulator and in road trials and one other subject had participated in road trials. The volunteers were paid 30 Euros for the two-hour experiment.

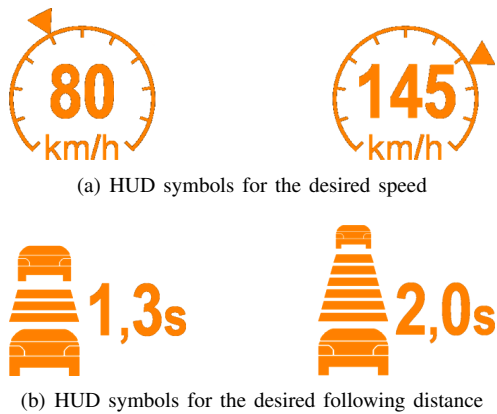


Figure 4. Visual Feedback in the Head-Up Display

### 3.2. Apparatus

The experiment was run in a fixed-base driving simulator with a 40° field of view. Subjects drove a modified BMW convertible with automatic transmission and simulated motor sounds on a two-lane rural road course with long curves and some villages in between. The driving scene was projected at a resolution of 1024x768 pixels and 24-bit colour onto one screen located 3.5 meters from the driver. Two interchangeable, wireless steering wheel inlays were developed to house the steering wheel controls, whereas the speed control for the divided concept was mounted permanently in the dashboard. For the Head-Up Display, we incorporated the DWARF framework [6] as a component-oriented toolkit to easily implement and test prototypes of the driver-vehicle interfaces. Finally, the Dikablis [7] helmet-mounted eye-tracking system was used to generate videos of eye glance behaviour.

### 3.3. Procedure

Upon arriving at the driving simulator, participants completed a demographic questionnaire and read a description of the driver controls for the ACC system. Once finished, they entered the vehicle, adjusted the seat and the eye-tracking system was calibrated. The drivers subsequently drove one practice round with eye-tracking (12 minutes). For each concept, drivers repeated practice tasks while parked and subsequently while driving until they could complete the task and stay in the lane while driving at least 80km/h. For the experimental trials, the participants drove the same ru-

ral road course as in the practice trial, but were given 18 verbal instructions from the experimenter to change the ACC settings. The order of the control concepts was counterbalanced between participants, but the task order was identical for both concepts. After completing the experimental tasks with both concepts, the drivers were interviewed about their subjective opinions of the ACC controls.

### 3.4. Experimental design

A within-subjects design was used, with all drivers using both ACC concepts. In order to examine only the task of changing the ACC settings and not the task of driving with ACC, the ACC functionality was disabled. Therefore, the drivers had to maintain proper speed (based on the traffic signs), following distance and lane position.

#### 3.4.1. Independent variables

The independent factors were *concept* (divided, integrated), *task type* (speed, distance or both) and *task length* (short or long). See Table 1 for descriptions.

#### 3.4.2. Dependent variables

The dependent variables included task performance, driving performance, glance behaviour and subjective measures [8]. The *task performance* measure was the time to complete the various tasks. The measurement of the task time started directly after the verbal instructions were given and ended when the correct value was shown in the HUD and the driver's left hand returned to the starting position.

The *driving performance* measures were an indication of how well the driver could maintain the proper speed (speed deviation and average speed difference) and lane position (lane deviation, lane departure time, steering angle variation and large steering corrections). Other than the measure of large steering corrections [9], these measures were defined in the HASTE (Human Machine Interface And the Safety of Traffic in Europe) Project [10].

The measures of *glance behaviour* were an indication of driver distraction and workload. For the analysis, the driver controls and displays were classified as "off-road". The total glance time "off-road" and number of glances "off-road" were calculated based on a manual off-line analysis of the eye glance videos.

Table 1

Description of the independent factors

Factor	Level	Description
ACC concept	divided	The desired speed is set on the dashboard and the following distance is set on the steering wheel
	integrated	Both the desired speed and following distance are set on the steering wheel
Task type	speed	Adjust the desired speed
	distance	Adjust the desired following distance
	both	Adjust both the desired speed and following distance
Task length	short	A small adjustment. The setting required only 1-3 clicks (e.g. 5 km/h faster)
	long	A large adjustment. The setting required 5-16 clicks (e.g. 40 km/h faster)

The *subjective measures* served to complement the objective data. The drivers opinion of their task performance (i.e. the usability of the controls) and their preference of ACC control and control location were asked in an open interview with fixed questions. Questions were of various formats, including ranking, scoring, short answer and long answer.

An initial analysis of the data indicated that all dependent measures were not normally distributed ( $p < 0.05$  according to the Kolmogorov-Smirnov Z test). In addition, some of the measures were categorical (e.g. usability scores). Therefore non-parametric tests were used to find significance, in particular the Mann-Whitney U Test (Z values) for testing the difference between two groups and the Kruskal-Wallis H Test ( $\chi$  values) for three or more groups.

#### 4. Results and Discussion

There was no statistical difference between the task times for the divided and the integrated concepts ( $Z = -0.604$ ,  $p = 0.546$ ). On the contrary, the task times differed significantly between the three task types ( $\chi^2 = 114.654$ ,  $p < 0.001$ ). The adjustment of both controls together took significantly longer than the individual adjustment of the speed ( $Z = -8.941$ ,  $p < 0.001$ ) or distance ( $Z = -9.533$ ,  $p < 0.001$ ), as can be seen in Figure 5. With both concepts, the median time was 4.5 sec to adjust the speed and 4.3 sec to adjust the following distance, whereas the adjustment of both settings required 9.1 sec with the divided concept and 7.5 sec with the integrated concept. The task length also had a significant effect on the task time; the long tasks took approximately twice as long as the short tasks ( $Z = -10.479$ ,  $p < 0.001$ ). When considering both the task type and task length, the task times for the both-long task (i.e. drivers had

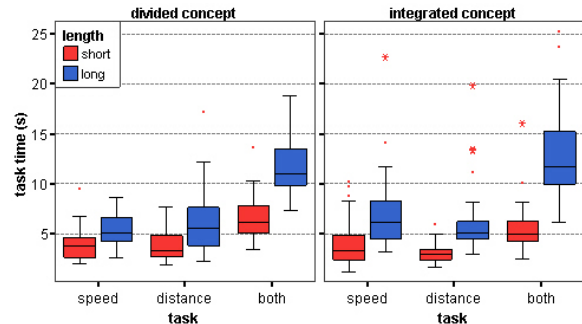


Figure 5. Task times per concept, task and task length

to make large adjustments to both controls) were considerably longer than all other task-length combinations, with a median of 11.0 sec for the divided concept and 11.7 sec for the integrated concept.

The ACC concept did not influence the speed-keeping measures, but the type of task did have an effect. Participants drove significantly slower when adjusting both the speed and distance controls compared to adjusting only one setting ( $\chi^2 = 12.706$ ,  $p < 0.01$ ). For the *speed* and *distance* tasks, the mean speed was 2.1 km/h respectively 1.5 km/h below the posted speed limit, whereas the mean speed was 6.4 km/h below the posted speed limit for the *both* task. On the contrary, the task length did not affect the speed difference measure. Furthermore, the speed deviations were significantly larger when both controls were adjusted as compared to only one control ( $\chi^2 = 24.626$ ,  $p < 0.001$ ), and also significantly longer for the long tasks compared to the short tasks ( $Z = -5.666$ ,  $p < 0.001$ ). These findings are portrayed in Figure 6.

The two concepts did not influence the driver's ability to maintain lane position; there was no significant difference between concepts for lane deviations and

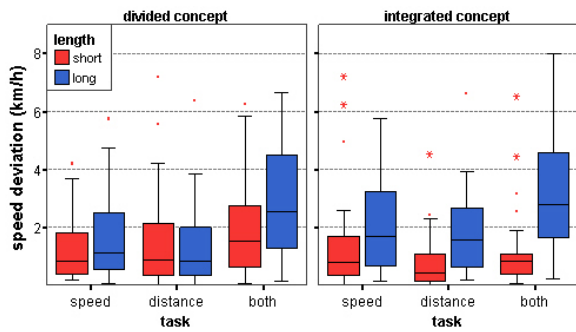


Figure 6. Speed deviation per concept, task and task length

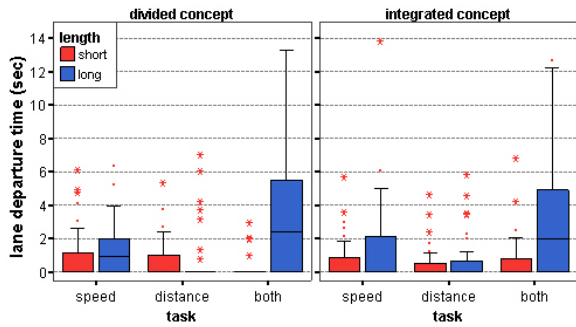


Figure 7. Lane departure time by concept, task and task length

lane departure time. On the other hand, the type of task did have a significant effect. The lane deviation was significantly higher (median 33 cm) when both the speed and distance were set ( $\chi^2 = 35.344, p < 0.001$ ) as compared to changing only one setting (median 21 cm for *speed* and 19 cm for *distance* tasks). This coincides with a significantly higher lane departure time for this task ( $\chi^2 = 12.641, p < 0.01$ ) compared to the *speed* and *distance* tasks (Figure 7). In addition, the lane deviation and lane departure time were also significantly greater for the long tasks compared to the short tasks ( $Z = -5.115, p < 0.001$  and  $Z = -4.764, p < 0.001$  respectively). Lane departures appear to be very sensitive to large adjustments with the speed control.

Similar to the lane-keeping measures, the steering measures also did not differ between the two ACC concepts, but instead differences were observed between tasks. Steering angle variation differed significantly between all three tasks ( $\chi^2 = 22.953, p < 0.001$ ). This steering activity was the smallest when drivers adjusted the distance (median =  $1.26^\circ$ ) and the largest when drivers adjusted both controls (median =  $1.80^\circ$ ).

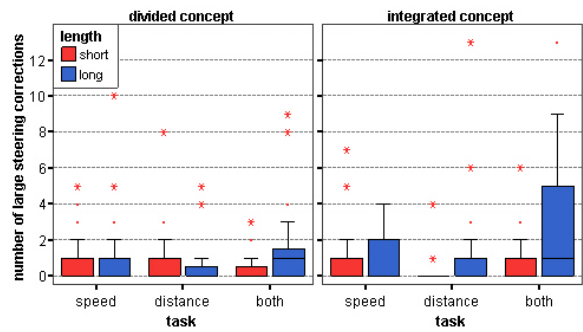


Figure 8. Number of large steering corrections by concept, task and task length

Drivers also had larger variations in steering and more large steering corrections for the long tasks compared to the short tasks ( $Z = -3.497, p < 0.001$  and  $Z = -3.006, p < 0.01$  respectively). In addition, drivers had significantly fewer large steering corrections while adjusting the distance control compared to adjusting only the speed control or both controls ( $\chi^2 = 13.967, p < 0.001$ ). This main effect was primarily caused by the integrated concept, as can be seen in Figure 8. For example, 86% of the *short distance* tasks with the integrated concept were completed without any large steering corrections compared to only 39% of the *long both* tasks. Therefore the steering control of the integrated concept appears to be main cause of the large steering adjustments.

The number of glances "off-road" depended significantly on the type of task ( $\chi^2 = 90.75, p < 0.001$ ), as shown in Figure 9. There was no significant difference between the ACC concepts, though there was an interaction between concept and task type. With the divided concept, drivers required the least number of glances while adjusting the speed (median of 3) and the most glances while adjusting both controls (median of 5). On the contrary, drivers required the least number of glances while adjusting the following distance with the integrated concept (median of 3) and the most while adjusting both controls (median of 5).

The total glance time "off-road" was significantly smaller when drivers used the integrated concept ( $Z = -2.211, p = 0.027$ ). It also depended on the type of task ( $\chi^2 = 94.511, p < 0.001$ ) and the task length ( $Z = -9.656, p < 0.001$ ), as is portrayed in Figure 10. For example, the *long both* tasks had the longest total glance times with means of 7.2 sec for the divided

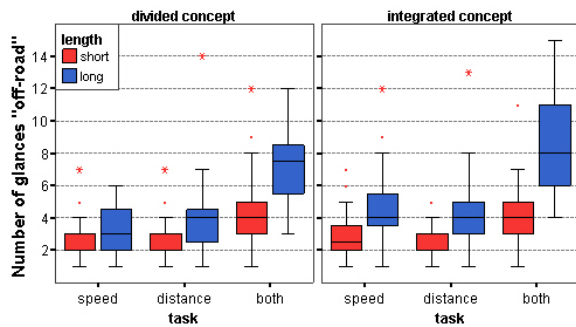


Figure 9. Number of glances "off-road"

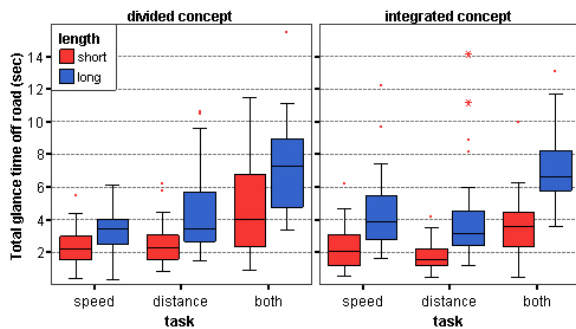


Figure 10. Total glance time "off-road"

concept and 7.8 sec for the integrated concept. On the other hand, the *short distance* tasks had the shortest total glance times with means of 2.4 sec respectively 1.7 sec for the two concepts.

Subjectively, most drivers preferred the integrated concept; they rated the usability and appearance higher, and considered it to be less distracting and faster to use. Ten of 12 drivers wanted the ACC settings to be displayed in the HUD and 11 drivers wanted the controls to be located together on the steering wheel.

## 5. Conclusions

Based on the experimental results, several design recommendations can be supported. Firstly, the type and length of task had a significant effect on the driving performance and glance-based measures. Therefore, drivers should only make small changes to one control at a time. Secondly, controls should be within easy reach of the steering wheel and within sight of the driver. Thirdly, the controls should employ a form of haptic feedback (e.g. click stops) to permit fast,

"blind" operation. Finally, rotational controls should not be used on the steering wheel, since the rotating frame of reference is confusing and difficult to operate.

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