

In-Vehicle Communication and Driving: An Attempt to Overcome their Interference

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Abstract

Within the framework of the project S.A.N.T.O.S.² (adaptive driver assistance) research is conducted with the aim to adapt driver assistance in a manner to counteract possible influences of in-vehicle communication on driving. A prerequisite towards this aim is a thorough understanding of the effects of communication on driving. An experiment is presented in which three prototypical driver-car interactions were used: a visual and an auditory information processing task and a manual operation task. According to Multiple Resources Theory these different in-vehicle communications are to interfere with the driving task in a varying amount and pattern. The effects of these communication tasks were examined in a driving-simulation task in which one half of the participants had to maintain their driving speed without and with a preceding car on a straight road while the other half of the participants had to control their lateral position on a curvy road while driving at a recommended speed. Overall, thirty subjects took part in a mixed between-within subject design. First of all, we found distinct changes in the driving behavior caused by the communication tasks. Most strongly, the control of the lateral position of the car deteriorates. Second, the manual operation task causes the greatest interference with the driving task followed by the visual and the auditory information processing task. Third, the driving task has a negative effect on the performance in the in-vehicle communication tasks. These findings support the assumption that advanced driver support systems have to be adapted to different kinds of in-vehicle communication and gives indications of how to design this adaptation. A successful adaptation may also increase the acceptance of these adaptive driver assistance systems if they do not only improve driving behavior but also in-vehicle communication.

Introduction

Today, in-vehicle communication encompasses a wide range of functions with an increasing tendency. The most prominent example encouraging a heated public debate is the use of mobile phones while driving. Results from epidemiological studies (e.g., Redelmeier & Tibshirani, 1997, Violanti & Marshall, 1996, Violanti, 1997, Violanti, 1998) as well as from experimental studies (e.g., Alm & Nilsson, 1994, Alm & Nilsson, 1995, Becker et al., 1995, Briem & Hedman, 1995, Brookhuis, de Vries & de Waard, 1991, Fairclough, Ashby, Ross & Parkes, 1991, Green, Hoekstra & Williams, 1993, McKnight & McKnight, 1993) indicate that using a phone while driving may increase accident risk and change driving behavior. Thus, efforts are taken to counteract this risky behavior. In Germany, for example, a law will be passed this year allowing only hands-free use of mobile phones. As some of the results of the

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experimental studies cited above indicate that the negative effect of using a phone may not result from handling the phone but mainly from talking on the phone, this measure will have a dubious impact at best. However, completely banning the phone from the car in order to stop drivers from talking to someone on the phone will hardly be possible as in this case talking to passengers should also be prevented. Moreover, the technical industry is rapidly developing new communication devices for in-vehicle use as, for example, internet browsers with a decreased visual and increased auditory output.

Taking these developments into account strategies for coping with possible negative effects of in-vehicle communication have to be developed. Driver assistance systems may be a promising means to this end as they are designed to relieve the driver from some workload and to supervise and warn the driver if a dangerous situation arises which requires additional effort. If in-vehicle communication changes the driver's behavior, these changes may be counteracted by a driver assistance system which either detects changes in driving performance or detects an on-going communication, knows the effects of this communication on the drivers and can thus react to these expected changes in advance.

This approach was chosen in the project S.A.N.T.O.S (adaptive driver assistance³). Within this project, driver assistance systems (Heading Control HC: Maintenance of lateral position; Autonomic Cruise Control ACC: Maintenance of speed and keeping a safe distance to cars in front) are to be adapted to different types of drivers and driving situations, in-vehicle communication being one important situational factor. The general idea is to detect when the driver engages in a certain kind of in-vehicle communication and to adapt the driver assistance systems in a way which proves beneficial for the driver in this communication situation.

The major prerequisite of this strategy is knowledge about how different kinds of in-vehicle communication changes the driver's behavior in order to be able to counteract or to adapt to these changes effectively. To this aim typical categories of in-vehicle communication were chosen for an experimental investigation. For this selection the distinction between different input and output channels was taken from multiple resources theory leading to three prototypical communication situations. The effect of these in-vehicle communication types was examined in two driving-simulation tasks focussing either on lateral or speed/distance control of the car. From the experiment the effect of communication on driving behavior may be analyzed as well as the effect of driving behavior on the communication task as measures for the quality of performance in communication were also recorded.

Method

The driving simulator of the IZVW consists of a seat and console taken from a car and a projection system on the wall in front of this car (see Figure 1). The simulation runs on two PCs (233 MMX, 32 MB memory). One of these computes the car model (BMW 7xx), the sound model and stores the data. The other one computes the surroundings and the street and creates the graphics by means of a Diamond Fire 1000 GL pro graphics card. The data are stored with a frequency of 100 Hz. From those data, the following parameters were computed to describe the performance in the driving task: standard deviation of speed in [km/h], mean and standard deviation of the time gap towards the preceding car in [seconds], standard deviation of the lateral position in [meters], standard deviation of steering wheel velocity in [degrees per second] and standard deviation of the heading error in [degrees]. These parameters give the basic information about lateral and longitudinal control of the car. Moreover, these parameters de-

³ For further information, please visit our website at <http://www.santosweb.de>.

scribe aspects of driving which are influenced by the driver assistance systems HC and ACC. Therefore, the results may be used to adapt these systems to in-vehicle communication.



Figure 1: The driving simulator of the IZVW.

Three communication tasks were introduced: (1) a manual operation task that focuses on manual output and requires only some visual input and memory, (2) a visual information processing task which requires only basic vocal output, and (3) an auditory information processing task which also requires minimal vocal output. In the first task a person's name is presented on a computer screen. The driver has to select an address list by means of a joystick and then find the address of the person in this list by scrolling the list with the joystick. Both information processing tasks are adapted versions of the Baddeley Working Memory Span Test (Baddeley, Logie & Nimmo Smith, 1985). Simple sentences like "the bird translates the car" are presented to the subject who has to decide whether this sentence is meaningful or not (saying "yes" or "no"). After five sentences have been presented the subject is asked to give the number of correct sentences. In the visual condition the sentences are presented on the screen of the computer. In the auditory condition the sentences are presented by a speaker (using a sound card and small speakers). All three tasks were done for the whole time of driving. In the information processing task subjects were asked to request a new sentence whenever they were able to process it. In the manual operation task a new address could be requested whenever the one before had been found in the list. Performance in the manual operation task was described by the number of addresses that had been found per minute. For the information processing conditions the number of blocks (consisting of 5 sentences) per minute was computed.

Two driving tasks were used in the experiment. The first consisted of a straight road divided into four parts: First, subjects were to maintain an average speed of 90 km per hour (km/h) for 7.6 km. Afterwards a preceding car was introduced which was to be followed at an average distance of about 40 meters (this was trained beforehand). The preceding car drove with a speed of 50, 90 and 130 km/h, respectively, and was to be followed for 4.4, 7.8 and 11.0 km. This resulted in a time gap of 2.88 seconds at 50 km/h, of 1.60 seconds at 90 km/h and of 1.11 seconds at 130 km/h. Each of these four parts took the subjects about 5 minutes. For the present analyses, these parts of the straight road were combined. The second driving tasks consisted of a curvy road including combinations of three curvatures and three lengths. This road was 25.2 km long and took about 20 minutes to drive.

Overall, 30 students participated in the experiment (see Table 1 for the experimental design). Half of the subjects drove the straight road, the other half the curvy road. The subjects were randomly assigned to one of the three communication tasks. Each subject participated in an extended training session with the driving simulator. The communication tasks were also explained and practiced. As these tasks were very simple only a short practice was necessary. After the training session each subject did two experimental sessions: (1) 20 minutes driving without any communication task, (2) 5 minutes communication task without driving, and (3) 20 minutes driving with the communication task.

Table 1: Experimental Design. Each subject performed one of the communication tasks given in the rows either on a straight or a curvy road. Each subjects performance was registered while driving, during the communication task, only, and while driving and doing the communication task. The cells give the subjects' numbers.

| | Straight Road | | | Curvy Road | | |
|---------------------------------|---------------|------------------------------------|--------------------------------|---------------|------------------------------------|--------------------------------|
| | Session 1 | Session 2 | Session 2 | Session 1 | Session 2 | Session 2 |
| | Driving, only | Communication Task without Driving | Driving and Communication Task | Driving, only | Communication Task without Driving | Driving and Communication Task |
| Manual Operation | S01..S05 | S01..S05 | S01..S05 | S06..S10 | S06..S10 | S06..S10 |
| Visual Information Processing | S11..S15 | S11..S15 | S11..S15 | S16..S20 | S16..S20 | S16..S20 |
| Auditory Information Processing | S21..S25 | S21..S25 | S21..S25 | S26..S30 | S26..S30 | S26..S30 |

Results

In order to analyze the effect of the different communication tasks on driving behavior a 2 x 2 analysis of variance including the factors road (straight vs. curvy; between-subjects) and communication (without and with; within-subjects) was computed for each of the parameters given above with the exception of the distance towards the preceding car (mean and sd) as this was present at straight roads, only. For these parameters a t-test was computed. Table 2 and Figure 2 give the results.

Table 2: Results of the statistical tests. The table gives the p-values of the analyses of variance and the t-tests.

| | | Speed sd | Time Gap Mean | Time Gap Sd | Steering Velocity SD | Lateral Deviation SD | Heading Error SD |
|----------------------|---------------|--------------|---------------|-------------|----------------------|----------------------|------------------|
| Manual Operation | Road | 0.464 | - | - | 0.003 | 0.002 | 0.000 |
| | Communication | 0.006 | 0.101 | 0.076 | 0.002 | 0.021 | 0.005 |
| | Interaction | 0.021 | - | - | 0.448 | 0.199 | 0.937 |
| Visual Information | Road | 0.054 | - | - | 0.003 | 0.001 | 0.000 |
| | Communication | 0.020 | 0.714 | 0.388 | 0.003 | 0.183 | 0.001 |
| | Interaction | 0.039 | - | - | 0.028 | 0.617 | 0.022 |
| Acoustic Information | Road | 0.125 | - | - | 0.012 | 0.000 | 0.000 |
| | Communication | 0.010 | 0.108 | 0.270 | 0.248 | 0.037 | 0.974 |
| | Interaction | 0.457 | - | - | 0.951 | 0.084 | 0.726 |

When drivers perform the manual operation task standard deviation of speed increases when driving on a straight road. Mean and standard deviation of the time gap towards the preceding car increase slightly ($p = 0.101$ and $p = 0.076$, respectively). All parameters describing lateral control of the car are significantly affected in curvy as well as straight roads.

The influence of visual information processing is much smaller and is only found on the curvy road. Standard deviation of speed is increased as well as the standard deviation of steering wheel velocity and heading error.

For acoustic information processing only the standard deviation of speed increases. Standard deviation of lateral position is reduced. This reduction is slightly larger on the straight road than on the curvy road ($p = 0.084$ for the interaction).

To summarize these results:

- Manual operation deteriorates the longitudinal and lateral control of the car on straight and curvy roads.
- Visual information processing mainly influences driving behavior on the curvy road where longitudinal and lateral control deteriorates.
- In the acoustic information processing condition only the variation of speed was increased but no other significant negative effect on driving was found.

Besides these changes in driving by communication performance in the communication tasks is also influenced by driving. This was also tested by means of 2 x 2 analyses of variance (factor 1: without vs. with communication; factor 2: straight vs. curvy road) using the number of sub-tasks completed in each condition (manual operation: number of addresses; other

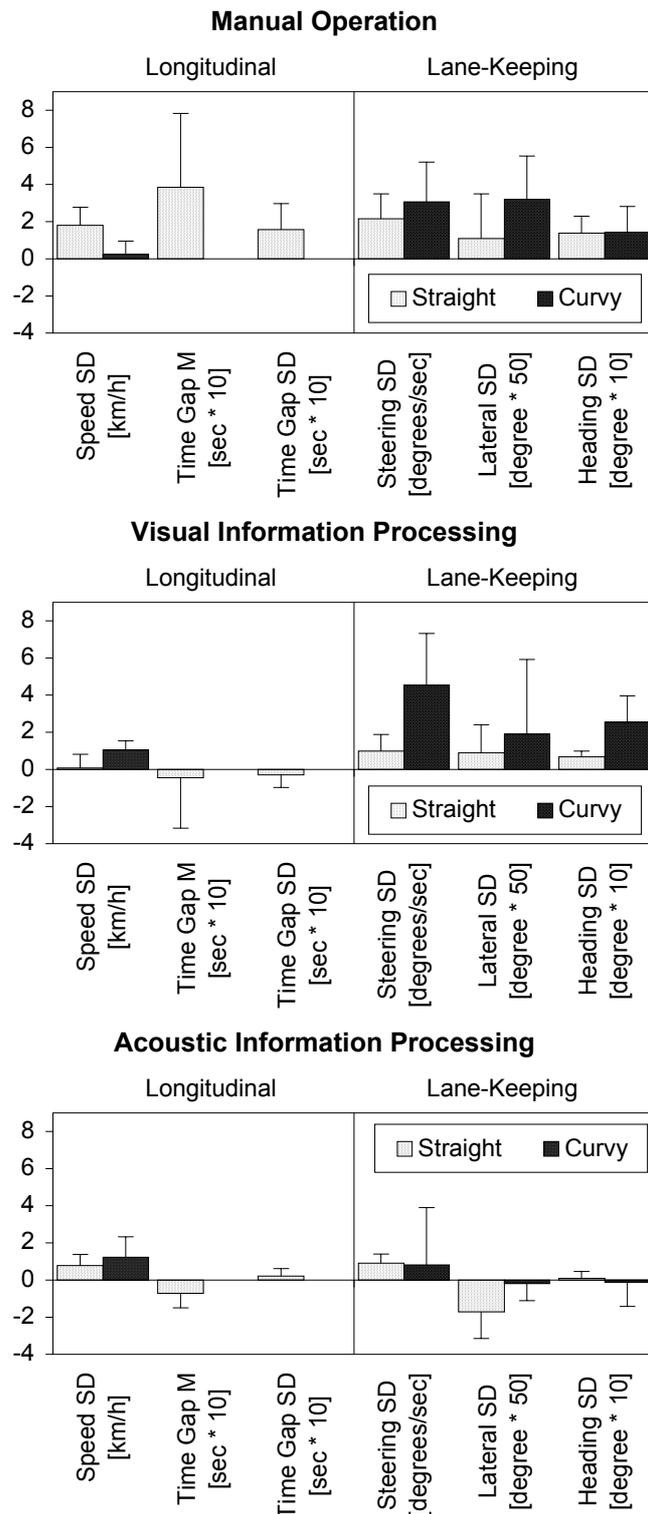


Figure 2: Changes in the different parameters due to the communication tasks. The figures give means and standard deviations of the differences between the condition with as compared to without communication task for the parameters described above (“steering”: steering wheel velocity; “lateral”: lateral deviation; “heading”: heading error).

conditions: number of blocks). A significant effect of driving was found for manual operation ($p = 0.000$) and visual information processing ($p = 0.006$) but not for acoustic information processing ($p = 0.549$). None of the main effects of road and none of the interactions were significant (all $p > 0.05$). Figure 3 shows the results. In manual operation and visual information processing the number of sub-tasks completed is much lower when driving than without driving. On the one hand these results show that driving also influences performance in secondary communication tasks. On the other hand these results support the interpretation that acoustic information processing and driving does not interfere.

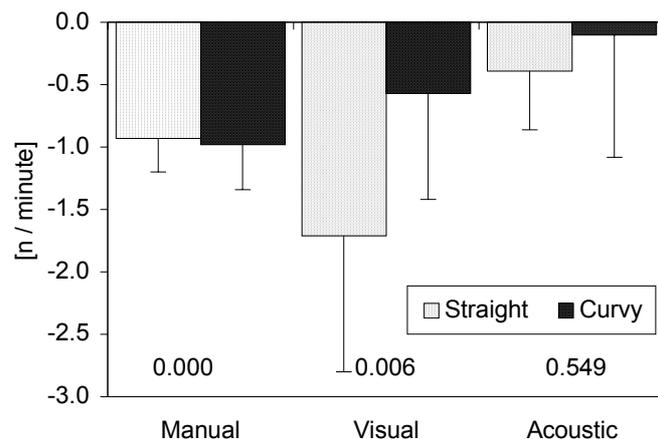


Figure 3: Effect of driving on the performance in the communication tasks. Depicted are means and standard deviations of the change (difference with minus without communication task) in the number of sub-tasks completed (manual operation: number of addresses; other conditions: number of blocks).

Discussion

The results presented show that not all communication tasks interfere with driving. Thus, it is preferable to present information acoustically and avoid visual output. Visual information processing leads to a decrease of driving performance especially on curvy roads (increased variation of speed, steering wheel velocity and heading error) where visual information processing of road characteristics is very important for the driving task. In order to counteract these effects a driver assistance system helping the driver to keep the lane would be desirable. Manual operation was the strongest disturbing factor with a similar decrease of driving performance on curvy roads as visual information processing but an additional decrease of performance on straight roads. There was also a tendency to increase the distance towards the leading car which might be interpreted as efforts to compensate for this deterioration. This stronger effect probably results from the fact that the manual operation condition includes visual information processing as well as motor action. Thus, when manual operation is performed driver assistance systems should not only assist in keeping the lane but also in maintaining a certain speed and keeping a safe distance towards the preceding car.

The results from the communication tasks show that interference is not restricted to driving behavior but also found in the performance of the communication tasks. Although the drivers reduce their involvement in the communication tasks when driving this reduction is not sufficient to prevent losses in driving performance. If driver assistance systems would be able to assist the driver in a manner which counteracts the effect of communication this might also help the driver to communicate more efficiently which could improve acceptance of the driver assistance systems.

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