Behavioural adaptation of drivers to warning and tutoring messages: Results from an on-the-road and simulator test

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Abstract: Drivers' reactions to warning and tutoring messages, triggered by violations or unsafe behaviour, were studied. Tests were carried out in an instrumented vehicle on the road, as well as in an advanced driving simulator. Information regarding local restrictions entered the vehicle at the moment of passing traffic signs through microwave communication.

Compared with a control group of drivers who had only received the instruction that their behaviour would be monitored, the experimental group showed the largest increase in law compliance in the condition where auditory feedback was given. Speed limit violations, following of lead cars at short headways and stop violations were significantly reduced in number and extent. Mental workload, however, as measured using a unidimensional scale, was increased in the case of tutoring.

Ratings of acceptance collected after the test rides showed that the drivers considered the system supportive, but their evaluation of comfort was negative.

Keywords: driver behaviour, human factors, mental workload, safety, speeding, tailgating.

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Introduction

In the next decade a major increase in technological devices in vehicles is expected as a result of ongoing progress in electronics. The impact on the driver of these in-vehicle devices can be scaled on a continuum from being purely informative to interventionist (Van der Laan *et al.*, 1997). Purely informational systems, for example RDS-TMC (Radio Data System - Traffic Message Channel, e.g. Chevreuil *et al.*, 1991) on a car radio, can easily be ignored, while some of the more interventionist systems may go as far as to actually take over control of the vehicle and reduce the driver's input to nil. In between these extremes, several driver support and feedback systems were and are being developed. While these systems might work well in terms of technical performance, effects on driver behaviour are not *a priori* positive. Most systems aim to support the driver, but the increase in quantity of in-vehicle equipment increases the demands on the driver's information processing system by added on-board displayed information (see, e.g., Dewar, 1988). Apart from this effect, the new equipment might lead to behavioural adaptations, which could be dangerous. Excessive reliance on systems such as Collision Avoidance Systems to maintain safe headway, will surely result in serious accidents in case of system failure. Other systems that actually take over control might turn driving into a vigilance task (Kantowitz, 1992). Finally, not only safety effects determine successful introduction and operation; sometimes even more important is the issue of social acceptance (Rothengatter *et al.*, 1991).

A potentially very effective, though possibly also a very interventionist system that enhances traffic safety is an in-vehicle enforcement system. Increased law compliance could have very beneficial effects on traffic safety. Accident analyses have shown that in as many as 92% of the accidents, the driver had violated at least one traffic law prior to the accident (Rothengatter, 1991). One of the ways to increase law compliance is by law enforcement. However, the techniques applied by the police in general have a very local effect, and disappear quickly after enforcement activities are suspended (e.g., De Waard and Rooijers, 1994). An in-vehicle enforcement system would not suffer from the limitations of on-site enforcement, and could monitor driver behaviour continuously.

In Europe the DRIVE/DETER project (DRIVE stands for 'Dedicated Road Infrastructure for Vehicle safety in Europe', DETER for 'Detection, Enforcement and Tutoring for Error Reduction') is concerned with the reduction of driver errors by monitoring and tutoring (Brookhuis and Oude Egberink, 1992). One of the prototypes that was developed in the project is an integrated tutoring and enforcement system. This system, which compares a selection of driver behaviours to what is legally allowed, was built into a car and tested on a public road. Previous tests with the prototype in a driving simulator showed that drivers behaved in a more law-abiding way if the tutoring and enforcement system was switched on (De Waard *et al.*, 1994; submitted). Important differences between drivers of different capabilities were found. Elderly drivers tended to make use of the system's warnings as driver support, for instance when a speed-limit sign was missed, and in particular these drivers could become dependent upon the system.

In a simulator the communication between vehicle and road infrastructure is optimal, i.e. information displayed on signs are always conveyed to the vehicle. In the real world this is more difficult, communication between road environment and vehicle could fail. Also, validation of the system in the real world is a logical next step after simulator trials. Therefore, an on-the-road test of the behaviour assessment system was planned and realised.

The configuration of the enforcement and tutoring system that was tested is shown in Figure 1. Local restrictions, such as a speed limit, enter the vehicle by on-site transponders, which are a part of a microwave communication system. The driver's behaviour as measured by car parameters, enters the *behaviour assessment system* and is compared to what is legally allowed, the *database normative behaviour*. When the *behaviour assessment system* detects a violation, the *tutoring system* is activated and an auditory warning is given to the driver. All detected violations are registered, with the possibility of law enforcement/punishment if the driver does not adapt his or her behaviour appropriately. The latter aspect is not shown in Figure 1, because it was not included in the experiment described below.

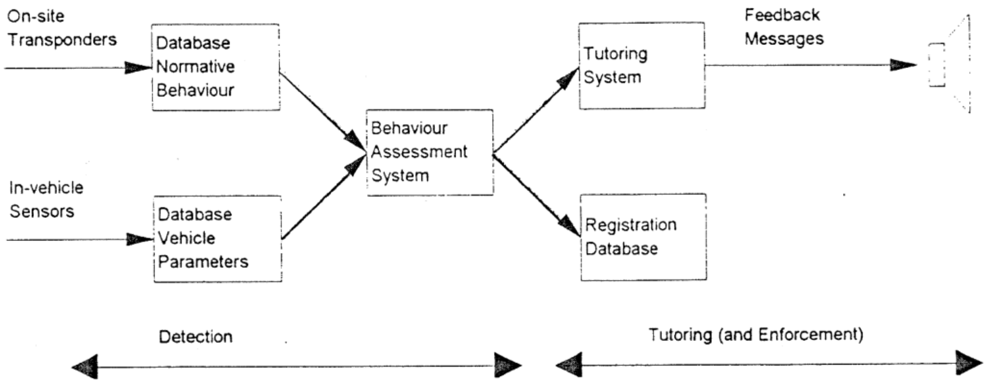

Figure 1 *Functional diagram of the tested DETER integrated tutoring and enforcement system.*

System performance, the driver's behavioural adaptation to the system as a result of tutoring messages, and acceptance of the system were the main issues in the field test. The experiment is described in detail in a technical report to the Commission of the European Union (De Waard and Brookhuis, 1995).

Method

A Renault 19 was equipped with a series of sensors. A microwave radar (Philips, operating at 76.5 GHz) was fixed in the front grill of the car. Also, a steering wheel movement sensor (full steering range) and a speed sensor (range 0 - 140 km/h) were installed in the car. Data regarding speed, headway distance and steering wheel movements were sampled on-line at 10 Hz by an industrial PC with a Pentium processor, and were stored on harddisk. The DETER behaviour assessment software, transposed to LabView also ran on this PC (Brookhuis and Kok, 1995).

Design

Subjects were recruited from the Traffic Research Centre's subject-database. Two groups were included in the experiment, an experimental and a control group. Subjects in both groups completed two nearly identical test drives (two 30 minute trials) in the demonstrator car. Auditory feedback messages regarding detected violations and short-following behaviour were only given during the second trial, and only to subjects in the experimental group. If messages were issued, normative behaviour was indicated (e.g., 'You're driving too fast, the current speed limit is 50'). Messages regarding speeding were only issued at the moment the speed limit (plus a 5% margin) was exceeded.

Messages regarding close following (less than 1 s time-headway) were repeated every 5 seconds if the driver did not adapt his or her behaviour. During all trials, violations of both the experimental and control groups were registered. The control group did not receive feedback messages during either of the two trials. This group was included for comparison with the experimental group, and to assess learning effects. At the start of the second trial subjects in both groups were told that a traffic-rule-monitoring system would be switched on during the test ride.

Test track

Subjects were guided by vocal route guidance messages that were triggered at specific points along the route. They were led over a variety of roads that included sections of motorways, A-roads and roads in built-up areas. In each trial they passed two stop signs, while a speed limit change occurred seven times. A fair amount of speed violation was expected because at certain spots subjects drove on wide lanes with relatively low speed limits. The large number of speed limit changes that subjects passed was also expected to enlarge the chance of speeding. One-way violations were enhanced by giving 'by accident' the wrong route guidance message (only during the second, experimental trial and only if subjects' safety was not at stake).

Communication

Information regarding speed limits, stop signs and one-way roads was conveyed to the car by means of a commercially available microwave system that had been adapted for this specific purpose. An antenna (NEDAP MIDS SAA-4S) / reader (MIDS V1) combination was installed respectively on top / inside the vehicle, while traffic signs were equipped with tags (labels, MIDS ML20). The microwave system worked at a frequency of 2.4-2.5 GHz. Positioning of the tags on the back side of traffic signs ensured that information regarding local speed limits did *not* enter the vehicle *too early*, i.e. not before a speed limit zone was entered. In case a label was missed by the receiver, the investigator could enter the label's code manually.

At stop signs a stop zone was defined in terms of time elapsed after passing the sign. A minimum speed of 0 km/h had to be detected in a time span of 10 seconds previous to detection of the stop-sign label.

Headway feedback was only given during Trial 2 and only to subjects in the experimental group. Feedback was given according to a time-headway criterion. Time-headway was defined as the time interval between the rear of a lead car passing a point on the road and the front of the following (experimental) car reaching the same point (see, e.g., Fuller, 1984). In case of a time-headway below 1 second (and a driving speed above 30 km/h) the verbal message 'You're keeping inappropriate distance' was issued.

Simulator

After the test drives in the car subjects performed two rides in the driving simulator of the Centre (Van Wolffelaar and Van Winsum, 1992, Van Winsum and Van Wolffelaar, 1993). Subjects drove in the same condition as in the on-the-road test, i.e. subjects in the control condition did not receive feedback regarding detected violations. Subjects in the experimental condition were provided with auditory feedback about violations in the second trial only. The same test-environment as described in De Waard *et al.* (1994, submitted) was used. A difference from the on-the-road test was that no feedback was provided in case of close following of a lead car. The simulator test was included to enable evaluation of the DETER system's effect on behaviour in that test environment. Since the primary topic of interest was system performance and the effects on driver behaviour in the field, the order of testing was fixed: subjects were first tested in the demonstrator car and then in the driving simulator. The dependent variables are listed in Table 1.

Table 1 Dependent variables (o = on-the road study only, s = simulator only).

Violations:

- Number and extent of speed violations
- Number and extent of stop violations
- Number of illegal one-way road entrances
- Number and extent of short headway violations (o)

Primary task parameters

- Speed (average and SD)
- Steering wheel movements (on straight road segments) (SD)

Subjective parameters

- BSMI score (mental effort rating scale, Zijlstra and Van Doorn, 1985)
- Score on nine items regarding acceptance of a tutoring and enforcement system (o) (Van der Laan *et al.*, 1997)

The tutoring messages were expected to reduce the number and extent of violations committed in the second trial relative to the first. A reduction in violations, albeit smaller, was also expected in the control group due to giving of the identical instruction as in the experimental group ('a monitoring system will be switched on that checks on traffic violations'). Based on results from previous simulator trials (De Waard *et al.*, 1994, submitted), mental load in the experimental group during tutoring trials was expected to be higher than in the non-tutoring sessions. A subjective rating scale (Zijlstra and Van Doorn, 1985) was used to assess mental effort. Acceptance of the system was evaluated directly after the test drives in the demonstrator car by means of ratings on nine acceptance items (Van der Laan *et al.*, 1997). Items on which the system had to be judged included 'usefulness', 'pleasantness', and ' superfluousness'. The different items load on either of two sumscales, a scale denoting the support (usefulness) the system gives and a scale designating the comfort (satisfaction) of the system.

Results

Twenty-nine subjects completed the on-the-road trials: 13 in the control condition, 16 in the experimental condition. Due to technical problems, the car-data sets were not complete for all variables and trials of all subjects. Five subjects suffered from simulator sickness, one subject was for practical reasons unable to perform the simulator trials while incomplete data sets reduced the total number of subjects that completed the simulator trials to 22.

Subjects were between 22 and 51 years of age (*M* = 38, *sd* = 7.1 years). They had an average mileage between 5,000 and 80,000 km/year (*M* = 26,000, *sd* = 19,000 km/year) and had held a driver's licence for at least 2 years (*M* = 17, *sd* = 6.8 years). Seventy-nine per cent was male. There were no significant differences on any of these variables between the two groups.

System performance

Although the antenna-tag system was not developed for use at high speeds, the system worked well, even on the motorway where the legal limit is 120 km/h in the Netherlands. None of the stop-sign tags, nor the tags at the entrance of the motorway sections, nor any of the other tags indicating the speed-limit, was missed (a total of 260 detections). The tag at the motorway denoting a 100 km/h speed-limit section was missed twice. In both cases subjects drove on the left-hand lane and a large lorry on their right obstructed communication between antenna and tag. There were no reports of any false alarms.

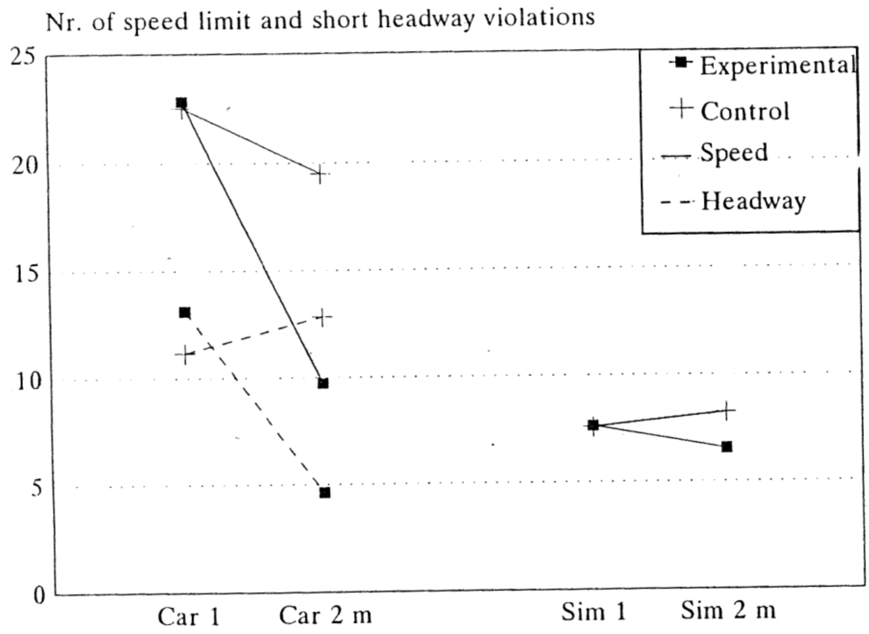

Figure 2 *The average number of speed and short headway violations that were detected in the demonstrator car (Car) and in the simulator (Sim). During the second trial (Car 2 and Sim 2) the experimental group received auditory tutoring messages. The control group had only been told that a system that monitored traffic rule compliance ('m' for monitoring) was in operation. All subjects were first tested on-the-road.*

Effects on violations

The experimental group committed significantly fewer speed violations when they received tutoring messages (Group x Trial interaction $F(1,21) = 5.96$, $p < 0.05$). The effect is particularly pronounced in the on-the-road trials (see Figure 2). As well as the reduction in number of speed violations, the average extent to which the speed limit was exceeded was reduced by the tutoring messages (see Figure 3, $F(1,18) = 11.56$, $p < 0.01$).

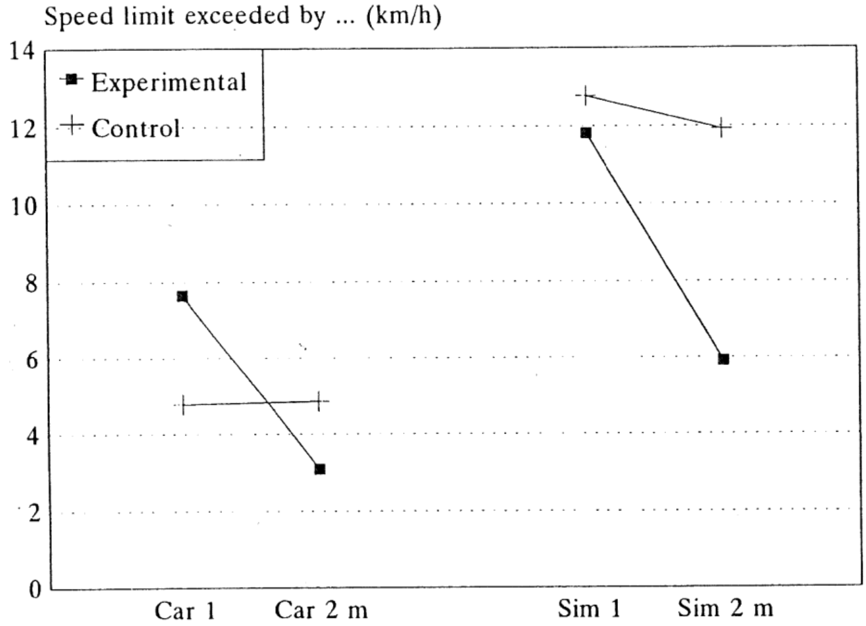

Figure 3 *The average extent to which the speed limit was exceeded per trial and group. The experimental group received during each second trial (Car 2 and Sim 2) auditory tutoring messages. The control group had only been told that a violation-monitoring system (m) was in operation.*

A 'rolling stop', common in the USA, is not allowed in Europe. Drivers had to come to a complete stop for at least one second at the stop sign. Per trial a maximum of two stop violations could be made. From Figure 4 it is evident that most subjects did not come to a complete stop. Once again, the tutoring messages were effective; the number of stop violations reduced ($F(1,21) = 6.14$, $p < 0.05$). The average stop speed, the minimum speed measured in front of a stop sign, was also affected by the system (demonstrator car: decrease of 2.4 km/h in Trial 2 in the experimental group, 0.7 km/h decrease in the control group; simulator: experimental group decrease in Trial 2 of 2.6 km/h, control group increase of 2.1 km/h, Group × Trial effect: ($F(1,17) = 7.10$, $p < 0.05$).

Following behaviour was assessed in the demonstrator car trials, only in cases where a lead car was present and detected, i.e. driving at a maximum distance of 127 metres. In figure 1 the average number of headway warnings that were (or would have been) issued are displayed (dashed lines). Warnings were given to subjects in the experimental group during the second trial, in cases where the adopted time-headway was below 1 s. Tutoring messages were repeated every 5 seconds if the driver did not increase his or her headway distance (Group × Trial effect: $F(1,26) = 6.54$, $p < 0.05$). Drivers in the experimental group increased their average time-headway from 2.01 s to 2.61 s. An increase in average time-headway found in the control group was of a different magnitude, from 2.10 s in Trial 1 to 2.18 s in Trial 2 (Group × Trial effect: $F(1,20) = 5.37$, $p < 0.05$).

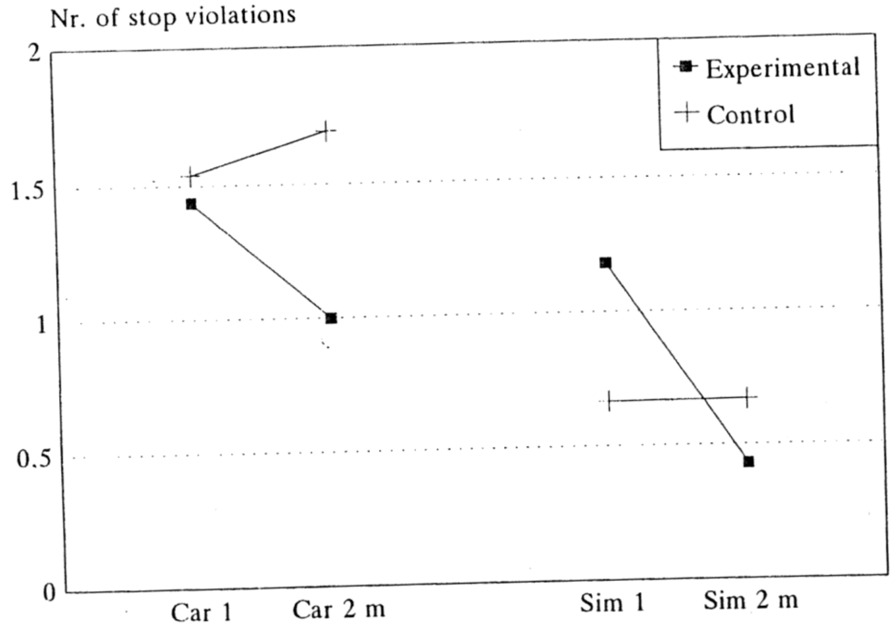

Figure 4 *Average number of detected stop violations per trial and group. The experimental group received during each second trial (Car 2 and Sim 2) auditory tutoring messages. The control group had only been told that a violation-monitoring system (m) was in operation.*

Only one subject entered the one-way road from the wrong direction. No tutoring message was issued because the subject was a member of the control group.

Effects on primary task parameters

Speed control was altered as a result of the tutoring messages (Multivariate: Hotellings $T = 0.74$, $p < 0.05$). Univariate tests show that this effect was caused by a lower driving speed ($F(1,17) = 10.14$, $p < 0.01$), similar to the effect shown in Figure 3. A decrease in speed variability was not statistically significant ($F(1,17) = 2.10$, NS).

Data on the *sd* in steering wheel movements as measured on road sections without curvature, give a more diffuse picture. A decrease in *sd* of the steering wheel movements can be indicative of more accurate steering (Macdonald and Hoffmann, 1980, De Waard *et al.*, 1995). On the two selected motorway sections the *sd* of the steering wheel movements was reduced as a result of the tutoring messages in the experimental group ($F(1,17) = 8.97$, $p < 0.01$). This effect was not found on a non-urban 50 km/h speed limit road. In the simulator trials no significant effects on the variance in steering wheel movements on straight sections was found.

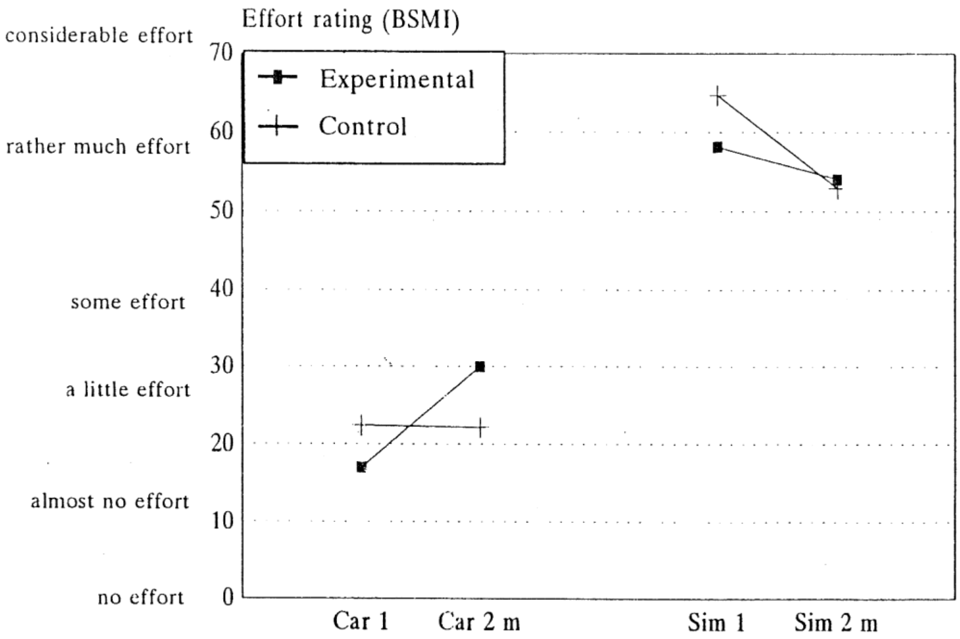

Figure 5 *Subjective ratings of effort to complete the task, per group and trial. The experimental group received during each second trial (Car 2 and Sim 2) auditory tutoring messages in case of detected traffic-law violations. The control group had only been told that a violation-monitoring system (m) was in operation. All subjects were first tested on-the-road.*

Effects on subjective parameters

In the earlier simulator trials (De Waard *et al.*, 1994, submitted) there was evidence for increased mental load during tutoring. Both a physiological parameter, reduced heart rate variability, and a subjective parameter indicated increased mental effort. In the present on-the-road trials a similar effect was found on the subjective rating scale, BSMI (Zijlstra and Van Doorn, 1985). In Figure 5 this effect can be seen (Car data only: $F(1,26) = 5.97$, $p < 0.05$). Also, driving in a simulator required significantly more effort than driving a normal vehicle ($F(1,21) = 48.0$, $p < 0.01$). Although Figure 5 gives the impression that the reduction in invested effort during the second simulator trial is larger for the control group, this effect is not statistically significant ($F(1,21) = 1.31$, NS).

Acceptance was evaluated by ratings on nine items that load on two scales. One scale denotes support or usefulness of the system, the other indicates comfort or pleasantness. Before the test drives the tutoring system was described and the subjects gave their judgement on the nine items. After experience with the system, directly after the demonstrator car trials, they gave a second rating. Average scores on the support and comfort scale are presented in Figure 6. For the control group no difference between before and after measurement was found on either of the two scales. The average support score of the experimental group did not alter as a result of experience with the system, however, the comfort score was affected in this group. Subjects rated comfort as lower after they had been confronted with the tutoring messages ($F(1,27) = 4.20$ $p < 0.05$).

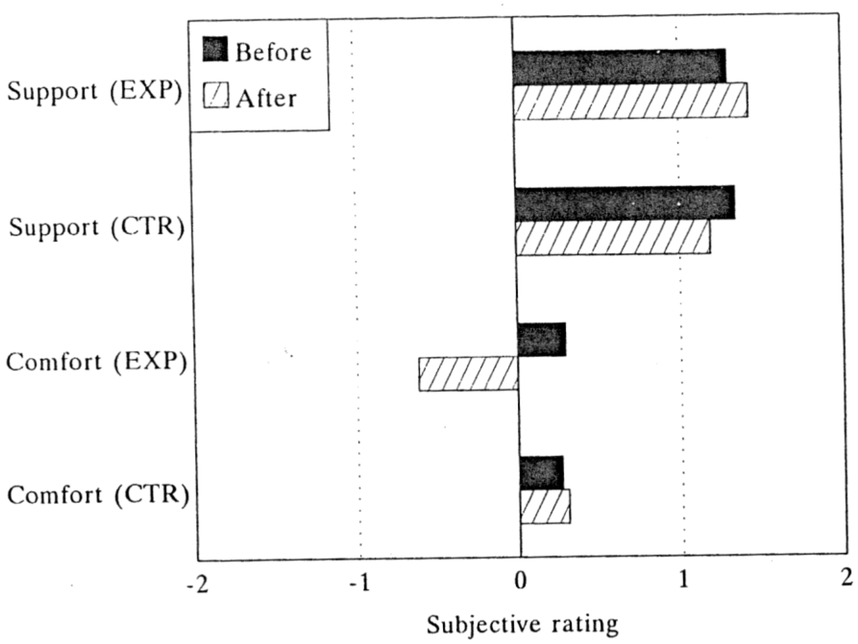

Figure 6 *Subjective ratings of acceptance, before and after the test drives, per group (EXP = Experimental group, CTR = Control group) on two scales ranging from –2 to +2. Only the experimental group received auditory tutoring messages in case of detected traffic-law violations. The support scale indicates usefulness of the system, the comfort scale satisfaction.*

Discussion and conclusions

Behavioural adaptation to an integrated enforcement and tutoring system was tested. The driver's speeding behaviour, headway distance and stop-sign compliance were assessed with and without feedback or tutoring messages. It was found that tutoring without commitment, sanctions were not applied, has clearly measurable, positive effects on law compliance. These results were replicated in a simulator test that followed the on-the-road trials. The decrease in violations was at the cost of a modest increase in mental effort with tutoring. In order to avoid warning messages, a behavioural adaptation is required that necessitates closer monitoring of the road environment and the speedometer.

The microwave communication between demonstrator car and road environment (i.e. tags) functioned very well. Only twice (0.8% of the passages) a tag was missed, with a clear cause that was expected in advance: a heavy goods vehicle was blocking communication between tag and antenna. No false alarms with respect to both the communication and the violation detection system were reported, with the exception of headway warnings. In heavy traffic on the motorway, sometimes 'false' headway warnings were given when an overtaking vehicle merged closely in front of the demonstrator car. Although following distance was below the criterion of 1 s time-headway, a warning to the driver in those cases would be inappropriate and disturbing. The problem could be solved by making a distinction between increasing and decreasing following distances. Warnings could be limited to detected decreasing time-headways. With the present radar and software this option is attainable.

The findings of positive effects on behaviour as a result of warning messages only, and ample acceptance of the supportive aspects of the system are both very encouraging. However, long-term behavioural effects are important, and from this experiment alone it cannot be concluded what will happen after a few weeks experience. Perhaps then a reward-penalty structure has to be coupled to repetitive violating behaviour in order to have comparable effects. However, the addition of violation registration will complicate matters very much, i.e. in legal administrative terms and in terms of social acceptance. Legal problems can be expected with respect to reliability of proof. Social acceptance is particularly of interest with systems that intervene or limit freedom. Therefore, the introduction of a tutoring (and enforcement) system is likely to be socially and politically most acceptable if restriction of the driver's freedom will improve safety and reduce traffic congestion and pollution (Brookhuis and De Waard, 1995).

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