Limiting speed, towards an intelligent speed adapter (ISA)

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Abstract

This study concerns the effects of a prototype intelligent speed adapter (ISA) on speeding in actual traffic. Twenty-four subjects were included in a test of effects of feedback on speed behaviour, mental workload and acceptance. Subjects drove an instrumented vehicle in normal traffic on various types of roads with different speed restrictions. Subjects completed the test route twice, half of the subjects received specific feedback in the second trial (experimental group), half of the subjects did not (control group). The groups differed in several ways, the most important being adaptation of their behaviour after feedback. Subjects in the experimental group behaved more according to traffic rules, in particular speed limits, than subjects in the control group. No significant differences in workload were found. Two types of feedback were tested to acceptance and were rated differently. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The persistent problems with respect to economic loss because of congestion and accidents have led to world-wide initiatives for large R&D programs to develop, amongst others, intelligent transport telematics (ITT) systems. One of the functionalities of such systems may be to facilitate the task performance of drivers by providing real-time advice, instruction and warnings. The latter types of systems are usually also described by the term “co-driver systems”. Co-driver systems may operate in advisory, semi-automatic or automatic mode (e.g. Rosengren, 1995), which concern, for instance, speed regulation systems (Rothengatter, 1991). Speed regulation as driver support system per se is different from speed regulation in (fully) automatic form, such as in autonomous intelligent cruise control (AICC) which is especially developed for and useful on...
motorways. Semi-automatic systems can be overruled by the driver, e.g. a system that gives compelling feedback about speed-limit compliance by increasing counter force on the accelerator when speeding. In the advisory mode, a speed regulation system is suitable for any environment and situation.

Speeding has a relatively well-known relationship to accident involvement. Salusjärvi (1981) reported an almost linear relationship between change in number of accidents and change of mean speed in Finland. Joksch (1993) found that the probability that a driver is killed increases with increased speed fits regression models with exponents as high as four, meaning that each km/h faster exponentially increases fatality risk. An average reduction of as little as 2–5 km/h could lead to a reduction of 10–30% in injury accidents (for a more elaborate overview, see Rothengatter, 1993). However, these effects seem less evident on motorways where a maximum speed of 120 km/h is allowed than on rural roads where a speed limit of 80 km/h is imposed (Wegman, 1991). On the latter type of roads the fatality rate is the highest in the Netherlands, while at the same time speeding is common and persistent.

1.1. Intelligent speed adaptation (ISA)

Through recent legislation in the Netherlands, the maximum driving speed is restricted by a speed limiter in the heavy types of lorries and coaches. As a consequence of this legislation, the number of heavy vehicles in which the maximum driving speed is restricted will increase in the coming years (Alink, 1992). The effect of these devices on fuel consumption, noise, air pollution, wearing of the tires and traffic safety is expected to be mainly positive (e.g., Almqvist, Hydén & Risser, 1991; Van der Mede, 1992; Wilbers, 1992). The obvious restriction of a mandatory speed limiter, is that it only prevents driving above the maximum allowed driving speed of heavy goods haulage vehicles, and is independent of a local limit in a specific road environment. An intelligent speed adapter (ISA) takes into account local restrictions, and adjusts the maximum driving speed to the posted maximum speed. When it comes to restriction of driving speed of private vehicles, the use of intelligent speed limiters is to be preferred due to further differentiation of speed limits for private cars compared to heavy goods vehicles. A non-intelligent speed limiter is set at the maximum allowed driving speed for motorways (120 km/h), while the majority of a speed limiting system’s safety benefits can be attained on rural or A type roads (limit 80 km/h) and in built-up areas (50 km/h).

Intelligent speed limiters require communication between vehicle and a suitable information source. For exchange of information about the road class or local restrictions, one option is to equip traffic signs with transmitters, beacons or tags. At the moment a car passes such a sign, the new speed limit is to be conveyed to the vehicle. Examples of experimental car-infrastructure communication can be found in Sweden (Nilsson & Berlin, 1992; Palmquist, 1993; Persson, Towliait, Almqvist, Risser & Magdeburg, 1993) and the Netherlands (De Waard & Brookhuis, 1995, 1997). Another option would be an advanced map-based information system, mediated by GPS (Almqvist & Nygard, 1998).

In general, a standard speed limiter is an intrusive system that restricts speed control, i.e. the device sets the maximum possible driving speed. An intelligent speed limiter is able to set this maximum speed in accordance with local posted legal limits. A less intrusive device is a system that provides the driver with feedback about local limits, for instance, on a small display.
Acceptance of the feedback type systems can be expected to be higher than of a strict, standard speed limiter, because behaviour is less restrained (cf. Brookhuis & Brown, 1992). Results from a questionnaire survey demonstrate that a slight majority of people consider an indicator of speed-limit violations useful, while only 35% of the respondents were of that opinion with respect to a speed limiter (Hagen & Fokkema, 1990). Another advantage of the feedback systems, as opposed to actual speed restriction, is that speed violations can sometimes be advantageous for traffic safety, e.g., there are instances in which a (perhaps misjudged) critical overtaking manoeuvre is faster and safer performed if the limit is exceeded for a short while.

Observation of behaviour at the level of driver reactions to these systems is of primary importance. In addition to individual reactions, interaction with other traffic that is not equipped with speed limiters is also important. In such a ‘mixed traffic situation’, cars with speed limiters could easily annoy drivers of cars that are not restricted and vice versa (Almqvist et al., 1991; Persson et al., 1993). These types of interactions deserve at least some attention in behavioural studies as well. Therefore, an effort was undertaken in the Netherlands to develop a prototype intelligent speed adapter that leaves the driver in control. For a start, this resulted in the development of a continuous feedback display in close proximity of the speedometer indicating the current speed limit, quite similar to the CAROSI system (Nilsson & Berlin, 1992). A central part of the CAROSI (CAr ROadside SIgnalling) system is the instrument panel, which includes not only standard displays such as the speedometer, but also contains sections on which roadside information is displayed. Amongst these is the posted speed limit, which is displayed below the speedometer. The major advantage of giving feedback by displaying the speed limit inside the car is that this information remains continuously visible instead of only being visible at the moment a sign is passed. This might reduce speeding because of general unawareness of the limit, which has been found in the Netherlands before (e.g., Steyvers, De Waard, Jessurun, Rooijers & Brookhuis, 1992; De Waard, Jessurun, Steyvers, Raggatt & Brookhuis, 1995).

A special version of the latter type of feedback display was developed for implementation in the institute’s experimental test-vehicle. Whenever the speed limit is exceeded the colour in which the speed limit is displayed changes from green (‘complying to the limit’) to amber, or yellow, (‘warning that the limit is passed’). In case the speed limit is exceeded by more than 10% the colour changes from amber to red (‘the limit is definitely violated’), and then an additional, auditory warning message is issued (see also De Waard, Van der Hulst & Brookhuis, 1999; De Waard & Brookhuis, 1995, 1997). These feedback systems are integrated in an existing system (see De Waard & Brookhuis, 1995; Brookhuis & De Waard, 1996), which is developed as an open system to integrate driver monitoring and feedback (sub) systems. In the present experiment this set-up is tested, letting subjects drive the instrumented test vehicle, with and without the feedback system. The purpose of the study is to investigate whether speeding can be reduced by simple in-car feedback.

2. Method

Twenty-four subjects, both male and female, were randomly selected from a existing subject-pool that contains over 1000 subjects. Selection criteria were age (25–50), driving license (>5 yr), driving practice (at least 5000 km/yr) and no experience with the test system. They were paid for
their participation. Upon arrival at the institute, subjects were first informed about in-vehicle information systems in general terms, and more specifically about the purpose of the study. Heart rate electrodes were fixed at appropriate places on the chest. Then a general questionnaire concerning personal data, such as driving experience and their ideas about speed restriction systems was completed. Thereafter half of the subjects drove the instrumented test vehicle over a fixed route and then performed a similar test in a simulator, half of the subjects in the opposite order. The simulator study is reported elsewhere (Brookhuis & De Waard, 1996) as the method, measures and analysis were too different from the on the road part to allow a useful comparison. Each of the test-rides consisted of two trials, first the baseline measurement, then after a short break, the second trial in which the subjects were told that a vehicle-sensor capturing system was monitoring their driving behaviour. Subjects were assigned randomly to either the experimental or control group. In the experimental group, subjects actually received feedback by the monitoring system, control-group subjects received no feedback. All subjects were instructed to drive as they would normally do in their own car.

The test rides in the instrumented test vehicle were in normal, quiet traffic under various conditions. Subjects were guided by sampled vocal route guidance messages. They were led over a varied route that included sections of motorways, A-roads and built-up areas, with speed restrictions of 50, 70, 80, 100 and 120 km/h. Each trial took about 35 min to complete. After each trial, subjects were requested to complete questionnaires concerning perceived workload. At the end of the whole test, subjects completed a general questionnaire again, asking for their ideas with respect to speed restricting systems.

2.1. Test vehicle

For the test rides on the road, the institute’s instrumented test vehicle was used (a Renault 19 GRI, see also Kok & Brookhuis, 1995). 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 hard disk. The integrated system software also ran on this PC (an extensive specification of the integrated system and subsystems is reported in Kok & Brookhuis, 1995).

Information regarding speed limits and stop signs were conveyed to the car by means of a microwave system adapted, not especially developed, for this specific purpose by an electronics manufacturer. An antenna/reader combination was installed on top, respectively, inside the vehicle, while traffic signs were equipped, at the back side, with tags. This microwave system operates at a frequency of 2.4–2.5 GHz. Positioning of the tags at 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 actually was entered. In this way it was avoided that drivers were ‘accused’ of speeding by the system when the new restrictions had not yet taken effect in the geographical sense.

In order to be (vocally accused of) speeding the driver had to exceed the speed limit by 10%. Feedback about local speed limits was provided only to subjects in the experimental group during feedback trials (i.e., the second series of rides). On the road the display indicating the speed limit in green (when keeping to the limit), amber (when exceeding the limit but less than 10%) or red (when exceeding the limit by more than 10%). The vocal message ‘You are driving too fast, the local limit is...’ was given at the instance the display’s colour changed from amber to red.
2.2. Workload

During the whole test, performance parameters and subjects' heart rate were registered as measures of workload (Mulder, 1992), whereas after each trial the self-report scale RSME (Rating Scale Mental Effort, see Zijlstra, 1993) was completed. In previous tests, both performed in the simulator (De Waard et al., 1999) and on-the-road (De Waard & Brookhuis, 1995, 1997), results showed that the tutoring messages increased driver mental load in a slight to moderate way. Both reduced heart rate variability and increased self-report scores indicated some increased effort.

2.3. Acceptance

Before entering the test rides and after the whole session, scores on nine items regarding acceptance of tutoring and enforcement systems (Van der Laan, Heino & De Waard, 1997) were requested from the subjects. From these, two compound scores were derived, a rate of usefulness and a satisfactory rate. After the test rides, additional specific questions about acceptance of the different feedback systems were posed.

3. Results

During the trials, it was noted that some of the subjects in the experimental group obviously explored the feedback system to test its behaviour or perhaps used it to stay in the marginal area (amber). Therefore, it was decided to focus on a parameter that reflects law compliance in time and to determine the proportion of time the limits were violated. Two parameters were determined, the proportion of time driving above the limit, i.e. the time the display was (or would have been) amber or red, and the proportion of time driving above the limit +10%, i.e. the time the display was (or would have been) red and an auditory message was (or would have been) issued. The “would have been”-condition is for the control group, the experimental group actually received the described feedback. From Fig. 1 it is clear that as much as 20–25% of the drivers are speeding in the strict legal sense. Between 5% and 10% of the time they are driving faster than the speed limit plus a 10% margin. The effect of the feedback system is significant for the latter parameter (Repeated measures ANOVA: Group × Trial interaction: $F(1,22) = 1.50$, ns for amber display, $F(1,22) = 9.39$, $p < .01$ for red display feedback).

In Table 1 the average time spent per speed limit area is shown. As there was no difference between the two groups these are presented together. It is clear that the largest proportion of time the limit was 50 km/h. From the right-hand part of the table it can be seen that giving feedback was also most effective in the 50 km/h areas. In the brief time the speed limit was 100 km/h, a short stretch of less than 1 km of motorway, the experimental group violated the limit more than the control group. The causes of this difference, already present during the first trial, are not clear.

During the feedback-trial the extent to which the limit was exceeded was on average lower by four km/h for the experimental group and nil for the control group. However, the interaction between groups and feedback is not significant (Group × Trial interaction $F(1,18) < 1$, ns).
Apart from determining the duration and extent of speeding behaviour, average speed was also calculated on selected road segments with a speed limit of 50 and 120 km/h. The difference between Trial 1 and 2 is significant for both average speed \( F(1,17) = 6.0, p < .05 \) and variability (SD) in driving speed \( F(1,17) = 10.4, p < .01 \). The interaction Trial × Group does not attain the level of statistical significance for the parameter “SD of driving speed” \( F(1,17) = 2.7, \text{ ns} \). The detailed data show that average driving speed on high speed roads increased with time-on-task (i.e., trials); the average speed increased from 114 to 117 km/h. Driving speed and variability (SD) in driving speed decrease mostly in the second trial, for the experimental group only. The average speed for the control group remained stable during both trials at 55 km/h, while the experimental speed for the control group remained stable during both trials at 55 km/h.

Table 1
The average time spend per speed limit area (in % of the total trial time, which was 35 min) and the average time speeding at a speed above the speed limit +10% (indicated as display red) \(^a\)

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<tbody>
<tr>
<td>Trial: 1 2((F))</td>
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<tr>
<td>Speed limit</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>50</td>
<td>72</td>
<td>76</td>
<td>11</td>
<td>11</td>
<td>14</td>
<td>6</td>
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<td>70</td>
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<td>2</td>
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<td>0</td>
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<td>0</td>
<td></td>
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<td>80</td>
<td>9</td>
<td>8</td>
<td>0</td>
<td>0</td>
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<td>14</td>
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<td>100</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Ctrl = Control Group, Exp. = Experimental Group, \(F\) = Feedback, provided to subjects in the experimental group only.

Fig. 1. Time driving above the limit and above the limit plus a 10% margin per group and trial. 1 = Trial 1, 2T = Trial 2.
group decreased speed from 56 to 51 km/h. The SD of driving speed decreased with 0.5 km/h for
the experimental group, for the control group no change was found.

3.1. Workload

Self-report ratings on the Rating Scale Mental Effort overall showed a tendency to evaluate the
amount of invested effort in the second trial as slightly lower \( F(1,17) = 4.04, p < .10 \). The effect,
however, is clearest for the control group; the experimental group remained at a constant level.
This interaction between Group and Trial also approached the 5% significance level
\( F(1,22) = 3.98, p < .06 \).

One physiological measure was registered; the subjects’ heart rate or ECG. Data were off-line
checked for artefacts and analysed in terms of four parameters: inter-beat-interval (IBI), variation
coefficient (normalised heart rate variability in the time domain), power in the mid-frequency
\((.08–.12 \text{ Hz})\) mental effort band and power in the high frequency \((.15–.50 \text{ Hz})\) respiration band.
The first two parameters are sensitive to general activation and effort, the latter two parameters (in
particular the mid-frequency component) are sensitive to mental effort. There were no effects of
feedback on any of the heart rate parameters.

Summarising, only self-reported mental effort during the feedback trials might indicate a rela-
tive slight increase in mental workload. Physiology and workload-related task performance did
not reflect any changes as a result of feedback.

3.2. Acceptance

Before the start of the first trial, a system that gives feedback when speeding was described and
subjects were asked to state their opinion about such a system. After the test rides, this was re-
peated in both groups resulting in before and after-test scores. Ratings on the acceptance items of
speed compliance feedback systems in general did not differ significantly between the control and
experimental group \( F(1,22) < 1, \text{ ns} \), nor did they differ between before and after-test measure-
ments \( F(1,22) < 1, \text{ ns} \). The compound usefulness was rated rather negatively, \(-1.04\) (cf., Van
der Laan et al., 1997), on a scale from \(-2\) to \(+2\), whereas the rating in terms of being satisfying
was slightly positive (+.16) on a scale with the same range.

After the test rides, subjects from the experimental group were asked to rate the effect of the
specific feedback system they just had experienced. This post-trial evaluation in terms of good/bad
and pleasant/not pleasant is given in Table 2. All drivers were asked whether they would accept
the different types of systems. Clearly, the continuous feedback display is very well accepted.

Table 2
Post-trial evaluation of the specific feedback system

<table>
<thead>
<tr>
<th>Feedback rating</th>
<th>Good (%)</th>
<th>Not-good (%)</th>
<th>Pleasant (%)</th>
<th>Unpleasant (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory message</td>
<td>73</td>
<td>0</td>
<td>21</td>
<td>54</td>
</tr>
<tr>
<td>Continuous display</td>
<td>91</td>
<td>0</td>
<td>82</td>
<td>0</td>
</tr>
</tbody>
</table>
4. Discussion

As in earlier experiments (De Waard et al., 1999; De Waard & Brookhuis, 1997), speed-reducing effects of feedback were found, but these were not as large as in previous experiments: 4 km/h only instead of about 10 km/h as found earlier. However, even at this level, this effect can substantially increase traffic safety. In the present experiment, continuous feedback on (posted) speed limits – and thus on rule compliance – was presented to the subjects, as opposed to incidental warnings in case of violations in the first two studies. This may explain a large proportion of the reduced effectiveness of feedback observed on the road. A close look at the data indicates a clear reduction in speed in the experimental condition in those cases where subjects clearly tended to violate the limit regularly, i.e. in the 50 km/h zones. Furthermore, from the data on percentage of time driving above limit (see also Fig. 1) it is clear that, at least some subjects used the continuous feedback to keep their speed in the margin of “limit to limit + 10%” (amber zone). It would be interesting to see whether drivers would do the same if the 10% margin is set below the actual speed limit.

Further studying the results of the speed data, it was apparent that the relevance to comply with the speed limit may well be different between different segments of the route driven, depending on the presence of, for instance, driveways, pedestrians, cyclists, etc. For post-hoc analyses, two 50 km/h speed-limit segments in which the subjects drove for a time period of 8 min were selected: one in a built-up area (high relevance), one in a rural area far away from pedestrians with a separate cycle path (low relevance). The hypothesis that ISA would interact with road segment was not supported. Although drivers in both the experimental and control group better complied to the limit in the built-up area (the display was red 4% of the time as opposed to 18% of the time in the rural area, \(F(1,22) = 42.1, p < .001\)), the interaction with display-feedback was not significant (\(F(1,22) < 1, \text{ns}\)). Apparently, in the present experiment ISA feedback does not add to increased rule compliance in a relevant environment.

From the acceptance data it follows that acceptance very much depends upon the specific feedback system. So far, continuous feedback was accepted best of all means of feedback by far. The ratings for the continuous visual feedback were unusually high and can perhaps even be considered as (highly) appreciated. For the introduction of driver monitoring systems in society this is a finding of major importance.

A new, unexpected effect of the compound feedback was found, a significant reduction in speed variability. One of the reasons for this is no doubt the earlier mentioned use of the amber colour feedback to stay in the margin of “limit to limit + 10%”. The implication of this finding is that the implied lower variability in driving speed could help to harmonise traffic, which is one of the candidate tools to reduce the number of accidents (see also Brookhuis & Brown, 1992).

In conclusion, because of its speed and speed variability reducing effect ISA could be a powerful tool to reduce the economic loss due to accidents and congestion. The feedback option, as tested, is highly appreciated which is a definite advantage with respect to introduction in society. The implementation by means of the microwave-tag system was only chosen for reasons of availability, a GPS-based communication system (Almqvist & Nygård, 1998) is more suitable for operational purposes in most conditions.
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References


