INTELLIGENT SPEED ADAPTATION: ACCEPTANCE AND DRIVING BEHAVIOUR ON RURAL ROADS

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ABSTRACT

The PROSPER (Project for Research On Speed adaptation Policies on European Roads) project, funded by the European Commission within the 5th framework program, was initiated to find answers concerning efficiency, public support, and implementation of road speed management methods, particularly Intelligent Speed Adaptation (ISA) in Europe. A part of the PROSPER project was to examine the effect of Human Machine Interaction (HMI) design for ISA could on driving behaviour and acceptance. Therefore, sixty-four experienced drivers participated in two experiments (32 each), in a moving-base research driving simulator. During the simulated runs with ISA, the speed limit was communicated through the ISA system. The ISA system consisted of an indication of the speed limit on the speedometer, and a gas pedal that could either be used as a haptic or tactile pedal, or as a dead throttle. Two versions of the haptic gas pedal were examined in experiment (a): a low-force ISA (easy to overrule, informative in nature) and a high-force ISA (stronger counter force, more compulsory in nature). Two other configurations were tested in experiment (b): a tactile pedal (a vibration on the gas pedal, informative in nature) and a dead throttle (completely restraining the driver from exceeding the speed limit). It was hypothesised that the closer to an informative type of ISA, the higher acceptance and the smaller the effects on driving behaviour would be. This hypothesis appeared to be valid, although for both driving behaviour and acceptance, not all four HMIs could be ranked unambiguously on the scale from no ISA to full ISA. In sharp curves, drivers appeared to chose a driving speed below the speed limit, irrespective of ISA. The specific road environment scenarios that were inserted to examine presupposed compensatory behaviour for experienced delay, indicated no signs of compensatory driving behaviour. Finally, it is concluded that the most promising sustainable and safety-improving approach in the future is the use of intelligent electronic systems such as ISA combined and integrated in the whole design of the road traffic system consisting of both the geometric design and dynamic traffic management.

INTRODUCTION

Speeding has been identified as an important factor in traffic safety in many studies (e.g., Várhely, A., Comte, S., and Mákinen 1998; Broughon, 1996). Violating the speed limit can be intended or unintended. Drivers have many reasons for intended speed limit violations, and in many cases the justification is found in the road design that allows for, or sometimes even invites to speed up above the speed limit. The main reasons for unintended speed limit violations are a lack of knowledge about the current speed limit and not being aware of the own driving speed. Intelligent Speed Adaptation (ISA) has proved to reduce speed and the number of violators (Carsten, 2002). One of the important issues regarding ISA is public support, since ISA bothers the drivers’ free choice of driving speed. Therefore, it is not only
about speed reduction, but also about acceptance and attitude towards ISA. In this paper a study on ISA is presented with respect to the effect of HMI design on driving behaviour and acceptance on rural roads, and the effect of road design on ISA is discussed.

The ISA study in this paper with respect to Human Machine Interface (HMI) design is part of the project PROSPER (Project for Research On Speed adaptation Policies on European Roads). The project PROSPER was initiated to find answers regarding the efficiency of ISA, road user behaviour and acceptance, and implementation strategies. PROSPER is funded by the European Commission. Additional to this ISA study a critical review is made of this study where ISA is discussed in the context of road design.

ISA covers a wide class of systems. On the one hand there is the advisory ISA (i.e. in-vehicle information of the current speed limit is provided to the driver, but speed is still controlled by the driver as in the situation without ISA). On the other hand there is full ISA (in-vehicle information of the current speed limit is provided to the driver, and this information is automatically passed on to the vehicle to set a limiting function for road speed).

For the HMI design, various components can be used to realise these ISA systems. Visual or auditory displays are logical candidates for the provision of speed limit information. This study emphasises on an active gas pedal. This pedal could be used e.g. to provide continuous haptic information by a counter force that is increased when the speed is above the limit. It could also be used as a tactile pedal that produces a vibration when the speed is above the speed limit. The third option of the pedal was a dead throttle that only functions as a gas pedal below the speed limit, above it has no function.

In the Swedish field trials auditory, visual and haptic HMI designs were used (Biding & Lind, 2002), and in the UK the dead throttle was mostly used for ISA (Várhely, Comte & Mákinen, 1998; Duynstee, Katteler & Martens, 2001), but the effects of HMI on acceptance and behaviour have not been systematically investigated in a controlled environment. Typically, in simulator/instrumented vehicle/fleet studies, one HMI has been selected. Then, results are obtained given that choice, but the influence of HMI aspects are not known. In an ISA research agenda (Carsten, 2002) one of the issues included the need to study the implications of different HMI designs. Which ones do users prefer? Which one produce the greatest amount of speed compliance? Therefore, two driving simulator experiments were performed, focussing on effects of HMI on user acceptance, and driving behaviour. This paper only focuses on the part that was necessary to evaluate the hypothesis below. For an overall description of both experiments, see Rook and Hogema (2005). The goal of the ISA study was to evaluate the following hypotheses:

1. When the level of control of ISA changes from advisory ISA to full ISA: (a) Acceptance of ISA is lower; (b) Effect on driving behaviour is lower (i.e. reduction of speed is less).

2. Users of ISA will compensate for their experienced (subjective) delay due to ISA, by adjusting their driving behaviour in terms of higher speed in curves (e.g., tendency to keep the speed at the speed limit instead of reducing it when driving into a sharp curve).

For ISA in general, it should be realised that compensatory behaviour only becomes an issue when ISA has a subjective effect on speed behaviour. Furthermore, the opportunities are necessary to compensate for the experienced delay.

The HMI used in the ISA study consisted of a visual indication of the speed limit in the speedometer, and a gas pedal of which four variants were tested. These variants, including the HMI are described in the method section.
METHOD

The ISA study was designed for a comparison of HMI designs, therefore a controlled environment was needed to assure that changes in driving behaviour, workload or acceptance were a pure result of the change of HMI. The study consisted of two separate experiments with 32 subjects each, carried out in the TNO research driving simulator. The driving simulator assures relative validation (i.e. comparison of conditions is valid), not absolute validation (i.e. absolute results are not valid). The experiments were first separately analysed through formal statistical analyses, second their results were compared qualitatively to each other. The first driving simulator experiment focused on an active gas pedal as the main HMI element. By manipulating the maximum force that an active gas pedal can apply, the level of control of an ISA can effectively be changed from advisory (just a moderate pedal force) to full ISA with limited opt-out (a strong pedal force that can only be overruled by a considerable force). The second driving simulator experiment focused on a tactile gas pedal that was considered to be advisory in nature, and the dead throttle that functions as a speed limiter and corresponds to full ISA. For both experiments only 'static' ISA was included, i.e., the ISA speed limit was always in line with the roadside speed limit. Furthermore, ISA was present in the entire road network.

Experimental Conditions

The experimental conditions of experiment (a) were defined as:

- **low-force ISA**: The active gas pedal produced a clearly distinguishable, and easy to overrule counter force, when exceeding the speed limit, which was mainly informative in nature.

- **high-force ISA**: ISA equipped with an active gas pedal with a more strongly dimensioned counter force and therefore much more compulsory in nature.

- **Control**: No ISA (as a reference for comparison of driving behaviour and workload)

The experimental conditions of experiment (b) were defined as:

- **tactile gas pedal**: The tactile gas pedal produced a clearly distinguishable vibration modulated by a block-signal, when exceeding the speed limit for approximately 1 percent, which was mainly informative in nature.

- **dead throttle**: ISA equipped with dead throttle, which restrained the driver from exceeding the speed limit. Additionally, a similar vibration as used in the tactile gas pedal is produced at the pedal position on the speed limit plus approximately 10 percent of the pedal stroke.

- **Control**: No ISA.

Within both experiments, the three conditions were all varied within subjects. The order of presentation of these conditions was balanced over subjects.

Experimental Environment and Scenarios

The test road environment consisted of an urban road environment with a regular speed limit of 50 km/h, and a rural road environment, with a regular speed limit of 80 km/h. The test road environment contained basically normal rural and urban sections, a sharp curve (radius of 150 m for about 400 m, and lower limit sections (70 km/h on rural for 2 km, and 30 on urban roads for 0.5 km). In this paper only the results on rural roads are discussed.
Other scenarios which are not further discussed in the results are: car following scenarios with a slower lead car, with and without overtaking possibilities (Rook & Hogema, 2005).

**Apparatus**

The experiment was conducted in the high fidelity driving simulator of TNO Human Factors (Hogema & Hoekstra, 2004; 1998). In this driving simulator the subject was seated in a BMW 318I mock-up, which is placed on a motion base with six degrees of freedom. The subject watched a large radial screen (with a field of view of 120 degrees circular, and 35 degrees elevation) on which the road and traffic environment were projected. Also the sound of the simulated vehicle (BMW) and of the traffic in the environment was generated. The experimenter was seated in a supervisor room next to the mock-up room, where he had access to the control system. He could watch the mock-up room by means of a video system; communication with the subject was possible by means of an intercom.

The HMI consisted of both visual feedback and feedback by an active gas pedal. The visual feedback was integrated in the speedometer. This way, the speed limit in relation to the actual speed can be seen in one single glance. This was performed by a circle of LEDs, of which only the LED corresponding with the speed limit was lit.

The basic principle of the active gas pedal as used in experiment (a) is a function where the gas pedal returns force changes with the gas pedal position. Without active gas, this relationship is a mechanical spring: the force increases (moderately) with increasing gas pedal position. With active gas, a second component is added, consisting of a considerably stronger spring. This second spring is only present for gas pedal positions beyond a threshold, which is continuously adjusted to the relationship between the actual speed and the speed limit. When the actual speed exceeds the speed limit, the threshold is reduced further and further, thus increasing the pedal force. When the actual speed is lower than the speed limit, the threshold is increased, thus ‘retracting’ the second spring, yielding the same force-position characteristic as without ISA. Consequently, when the driver maintains a force somewhat beyond the maximum of the normal gas pedal, the drivers’ foot will be pushed back until a gas pedal position is reached that yields a speed equal to the speed limit. The maximum pedal force for low-force ISA was 50 Newton, for high-force ISA it was 150 Newton.

The tactile gas pedal consisted of a normal pedal with a tactile vibrator (ca. 100 Hz) mounted on the back of the pedal. When the current speed was above the speed limit, a vibration modulated by a block of two seconds on, one second off was produced.

The dead throttle also functions as a normal gas pedal, but only in the range from zero speed to the speed limit. When the speed limit is reached, the remaining pedal stroke does not result in an acceleration. At a pedal position of approximately 10 percent beyond the pedal position at the speed limit, a block signal vibration is produced. The vibration is to inform the driver that the speed limit is reached, and the pedal can still be pushed down.

**Subjects and Protocol**

For each experiment thirty-two experienced drivers were selected from the standard TNO Human Factors traffic research subjects’ database. The selection criteria were: in possession of a driving license for more than 5 years, having driven more than 20,000 km per year, and an age between 25 and 60 years. Persons who participated in experiment (a) could not participate in experiment (b) as well. For experiment (a), the average age was 46 (s.d. 9), the average number of years in possession of a driving licence 25 (s.d. 10), and the average annual kilometres a year 27,300 (s.d. 17,000). For experiment (b), the average age was 44
(s.d. 8), the average number of years in possession of a driving licence 22 (s.d. 8), and the average annual kilometres a year 33,900 (s.d. 18,400). For both experiments 29 of the subjects were male, 3 were female. T-tests revealed no differences between experiments (a) and (b) in these variables. Participants were paid for their participation.

One experimental session took one morning, afternoon, or evening (approx. 4 hours). Subjects participated in the experiment in pairs and took their turns at driving in the simulator: while one was driving, the other completed questionnaires and could rest. The experiment was organised such that each participant performed six runs (for each condition one experimental run and three training runs) in three shifts. The first shift always included a general training run to get used to the simulator. The two experimental runs with ISA were preceded by a demonstration and a training run with the corresponding ISA condition. Participants were invited to play around during the training run to get acquainted with the system. The total time for each training run and experimental run was about 10 and 30 minutes, respectively. Note that the results of this study are based on these short term experiences, and may turn out differently for long term experiences (e.g., field trials).

After their arrival, participants were informed about the general nature of the experiment. An explanation was given on ISA and the specific ISA system they were going to drive with. Subjects got the general instruction that during the experimental runs, they were not supposed to stall, as if they needed their time to drive to a meeting. Further they were asked to drive as they normally do. Next, they signed a form of informed consent. Preceding the first run they started with a questionnaire concerning the attitude towards speeding, speed limiters and ISA. After each of the experimental runs subjects had to fill in a questionnaire concerning workload (NASA-TLX). After the experimental ISA runs a second questionnaire had to be filled in concerning the acceptance of the system they had just driven with.

Data Collection and Analysis

The collected data consist of objective measures registered in the driving simulator, and self-reported measures. The objective measures were logged during the experimental runs with a frequency of 10 Hz. The variables were speed of the simulated vehicle (m/s); covered distance (m); speed limit. Also speed and position data from nearby cars were logged. From these objective measures the free-driving speed was analysed. The free-driving speed is defined as the speed that subjects freely choose, without being influenced by any other traffic. It was analysed for normal rural road sections, sharp curves, and lower limit sections in a rural road environment. The self reported measures were obtained by two different questionnaires. After each experimental run drivers filled in the NASA Task Load Index (TLX) (Hart & Staveland, 1988). Results on workload are not discussed in this paper, they can be found in (Rook & Hogema, 2005).

The second questionnaire was used to measure the acceptance addressing the particular ISA system (Van der Laan, Heino & De Waard, 1997). This questionnaire had to be filled in after each experimental run with ISA. The questionnaire consisted of nine items:

**Usefulness**

1. useful-useless;
2. good-bad;
3. effective-superfluous;
4. assisting-worthless;
5. raising alertness-sleep inducing;
Satisfaction
6. pleasant-unpleasant;
7. nice-annoying;
8. likeable-irritating;
9. desirable-undesirable.

According to Van der Laan, the items were rated on a five-point scale. The questionnaire results were analysed in two ways. First, in the 'raw' analysis, ratings were simply analysed one by one. Second, the 9 responses were transformed to the 2 underlying dimensions usefulness and satisfaction. Usefulness was determined by averaging the ratings on the first 5 items that are mentioned. Satisfaction was determined by averaging the ratings with respect to the remaining 4 items.

Statistical Analysis

For the experiments, separate formal statistical analyses were carried out. Amongst the experiments, a qualitative comparison was made. Differences among means are tested for statistical significance by an Analysis of Variance (ANOVA). Differences between specific conditions are analysed by means of a Fisher least significant difference (LSD) post-hoc test. The use of this not too conservative test is justified, because differences among ISA conditions are expected.

RESULTS

Free-driving Speed

Mean Free-driving Speed

In this subsection the results are described with respect to the free-driving speed on normal rural road sections, with mainly straight roads or slight curves. The results of experiment (a) and (b) (FIGURE 1a and b) show a main effect of ISA (F(2, 60)=18.1; p<.001, and F(2, 62)=21.5; p<.001, respectively). Separate post-hoc tests for experiment (a) and (b) showed significant differences among all pairs (all p<0.01), except for the difference between low-force and high-force ISA, which was marginally significant (p=.057). The results are in line with the hypothesis that high-force ISA and the dead throttle (compelling in nature, full ISA, respectively) are more effective with respect to driving behaviour, than low-force ISA and the tactile gas pedal (informative in nature).
FIGURE 1  Mean free-driving speed as a function of road environment and ISA condition.

In a qualitative comparison of experiment a and b, it turns out that the mean speeds in the control condition for both experiments differ substantially. There is no straightforward explanation for this. It makes it rather senseless to perform formal statistical analyses including both experiments. Instead, TABLE 1 shows the absolute and proportional reductions in exceeding the speed limit due to the four ISA systems. The reductions are in line with the hypothesis. The dead throttle, which corresponds to full ISA, reduces the mean speed to the speed limit. The high-force ISA allows to exceed the speed limit, but obtains a high absolute and proportional reduction of the mean speed. The low-force ISA obtained a significantly smaller reduction compared to the high-force ISA. Finally, the tactile gas pedal obtained a considerably smaller reduction compared to the dead throttle. Compared to the active gas pedal, the reduction seems to be somewhere close to the low-force and high-force ISA, since the absolute reduction is quite small and the proportional reduction is close to high-force ISA.

TABLE 1 Reduction of the mean free-driving speed: absolute (km/h) and proportional (%) with respect to the range of control condition to 80 km/h speed limit) (ISA1: low-force ISA – tactile pedal; ISA2: high-force ISA – dead throttle).

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Mean speeds (km/h)</th>
<th>ISA1 reduction (km/h)</th>
<th>ISA2 reduction (km/h)</th>
<th>ISA1 proportional reduction (%)</th>
<th>ISA2 proportional reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>control 102</td>
<td>ISA1 93.3</td>
<td>ISA2 89.1</td>
<td>ISA1 8.7</td>
<td>ISA2 12.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISA1 39.4</td>
<td>ISA2 58.8</td>
</tr>
<tr>
<td>(b)</td>
<td>89.3</td>
<td>84.3</td>
<td>80</td>
<td>5.0</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISA1 53.7</td>
<td>ISA2 100</td>
</tr>
</tbody>
</table>

Free-driving Speed in Sharp Curves

With respect to the free-driving speed in a sharp curve on rural road sections (FIGURE 2a and b), in both experiments there was a main effect of road environment (F(1,31)=115.1; p<0.001, and F(1,30)=120.01; p=<0.001, respectively). Post-hoc tests showed that for both experiments the differences between normal and curve differed for all three conditions. The measure considered here is the mean speed in the sharp curves for both experiments. In experiment (a) there was a marginally significant reduction of the speed in the ISA conditions compared to control. In experiment (b) there was no difference between the conditions. The mean speed in curves was hardly or not affected by ISA. Thus, no signs of
compensatory behaviour were found. Note that the mean speed in the sharp curve was below the speed limit, and therefore the gas pedal functioned as a normal pedal.

**FIGURE 2** Rural road: mean free-driving speed as a function of ISA condition and road (normal versus sharp curve).

**Free-driving Speed at Lower Limit Section of 70 km/h**

With respect to the free-driving speed in sections with lower rural road limit (FIGURE 3a and b), in both experiments there was a main effect of road environment \((F(1,31)=68.1, \ p<0.001, \ \text{and} \ F(1,31)=201.0; \ p<0.001, \ \text{respectively})\), and a main effect of ISA \((F(2,62)=17.1; \ p<0.001, \ \text{and} \ F(2,62)=22.6; \ p<0.001, \ \text{respectively})\). A post-hoc test showed that for both experiments the differences between normal and the lower limit section differed for all three conditions. The absence of an interaction between ISA and the road environment indicates that the lower speed limit does not affect the reduction in speed obtained by ISA. Again there were no signs of compensatory behaviour.

**FIGURE 3** Rural road: mean speed as a function of ISA condition and speed limit.

**Acceptance**

ANOVAs were carried out on the nine separate items for both experiments, using ISA type (low-force - high-force, and tactile gas – dead throttle) as the only independent variable. The results are presented in **TABLE 3**. The ANOVAs showed that compared to the high-force ISA, the low-force ISA was rated:
more pleasant, less irritating, more assisting, and more desirable. Compared to the tactile gas, the dead throttle was more sleep inducing, which is in line with the result that workload is lower for the dead throttle than it is for the tactile gas pedal.

**TABLE 2 Acceptance results.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experiment (a)</th>
<th></th>
<th>Experiment (b)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low-force ISA</td>
<td>high-force ISA</td>
<td>tactile gas</td>
<td>Dead throttle</td>
</tr>
<tr>
<td>useful-useless</td>
<td>0.78</td>
<td>0.66</td>
<td>0.28</td>
<td>0.19</td>
</tr>
<tr>
<td>pleasant-unpleasant</td>
<td><strong>-0.09</strong></td>
<td><strong>-0.81</strong></td>
<td>-0.22</td>
<td>-0.28</td>
</tr>
<tr>
<td>good-bad</td>
<td>0.53</td>
<td>0.28</td>
<td>0.34</td>
<td>0.16</td>
</tr>
<tr>
<td>nice-annoying</td>
<td>-0.13</td>
<td>-0.41</td>
<td>-0.38</td>
<td>-0.58</td>
</tr>
<tr>
<td>effective-superfluous</td>
<td>0.81</td>
<td>0.56</td>
<td>0.19</td>
<td>0.50</td>
</tr>
<tr>
<td>likeable-irritating</td>
<td><strong>0.13</strong></td>
<td><strong>-0.66</strong></td>
<td>-0.38</td>
<td>-0.44</td>
</tr>
<tr>
<td>assisting-worthless</td>
<td><strong>0.91</strong></td>
<td><strong>0.41</strong></td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>desirable-undesirable</td>
<td><strong>0.34</strong></td>
<td><strong>-0.41</strong></td>
<td>-0.28</td>
<td>-0.53</td>
</tr>
<tr>
<td>raising alertness-sleep inducing</td>
<td>0.34</td>
<td>0.00</td>
<td><strong>0.34</strong></td>
<td><strong>-1.09</strong></td>
</tr>
</tbody>
</table>

**Bold is significant (p<0.05)**

Next, the data were transformed to the 2 underlying variables: ‘usefulness’ and ‘satisfaction’, as described in the method section. The resulting means are depicted in FIGURE 4a and b. ANOVAs were carried out and a significant effect of ISA type in experiment (a) was found for satisfaction: the mean for the low-force ISA (0.06) was higher than for the high-force ISA (-0.57) \( [F(1,31)=12, p<0.001] \). A marginally significant effect was found for usefulness \( [F(1,31)=3.2, p<0.1] \), showing that the mean usefulness was higher for the low-force ISA (0.68) than for the high-force ISA (0.38). A further series of t-tests revealed that:

- the means for usefulness were significantly larger than 0, for the low-force as well as the high-force ISA \( [p<0.001, p<0.05] \)
- the mean satisfaction for the low-force ISA did not deviate significantly from 0, i.e., was neutral \( [p>0.1] \)
- the mean satisfaction for the high-force ISA was smaller than 0 \( [p<0.01] \)
Thus, low-force ISA is more highly accepted than high-force ISA, the difference can be devoted to satisfaction, and not much to usefulness.

The ANOVA for experiment (b) did not result in significant effects regarding differences in usefulness or acceptance. A series of t-tests revealed that:

- the mean of usefulness of the tactile gas pedal (0.338) deviated significantly from 0 (p=0.031), the mean of usefulness of the dead throttle did not deviate from 0.
- the mean of satisfaction in the tactile pedal (-0.312) deviated marginally significant from 0 (p=0.056), satisfaction in the dead throttle (-0.445) deviated significantly from 0 (p=0.023).

Thus, in terms of usefulness, the dead throttle was neutral and the tactile gas pedal was slightly positive (although a difference between these systems was too small to be significant in the ANOVA).

From both experiments it appears that the usefulness of all four ISA systems is neutral to slightly positive, with respect to satisfaction it is neutral to slightly negative. The differences between both experiments with respect to usefulness and acceptance were too small to obtain any significant results.

**Willingness to have**

Subjects were asked whether they would like to have ISA in reality in their own car. The answers principally give an indication of the subjects attitude towards ISA. For the low-force ISA, 14 out of 32 subjects (44%) would like to have the system themselves. For the high-force ISA, 7 out of 31 subjects (23%) wanted to have the system. The difference between these proportions was significant (p<0.05, single-sided test). For the tactile gas pedal, 14 subjects out of 32 subjects (44%) would like to have the system, for the dead throttle, 8 out of 32 subjects (25%) would like to have the system. The difference between these proportions was marginally significant (p<0.1, single-sided test).
DISCUSSION AND CONCLUSIONS

The study described in this paper shows how the choice of an HMI, and therewith the choice for an Advisory ISA or Full ISA, affects driving behaviour, and the acceptance of ISA in general. The study also shows that ISA is not sufficient to keep drivers from violating the speed limit. This chapter gives conclusions on the effect of ISA on driving behaviour and acceptance, and it discusses the potential of the effect of road design on acceptance towards ISA.

Effects of ISA on driving behaviour

Without ISA, the mean free-driving speed was higher than the speed limit. In this setting the four ISA systems tested all reduced the mean free-driving speed. The proportional reduction in exceeding the speed limit (i.e., with respect to the range from the mean speed in the control condition to the speed limit) obtained by the dead throttle was the largest (100 percent). This was expected since this system does not allow exceeding the speed limit at all. A qualitative comparison shows that high-force ISA and low-force ISA obtained less speed reduction than the dead throttle. The high-force ISA still allowed for exceeding the speed limit, although quite some physical effort was needed, drivers did often drive faster than the speed limit. Therefore, high-force ISA reduces speed less than the dead throttle. Low-force ISA reduced speed statistically significant less than high-force ISA. The sequence of these three ISA systems on the scale from no ISA to full ISA is in line with the hypothesis. The position of the tactile gas pedal is somewhat ambiguous, sometimes close to low-force, and sometimes close to high-force ISA.

The mean free-driving speed in sharp curves when driving with ISA was lower than the limit, and did hardly or not differ from the speed in the control conditions. Therefore, it can be concluded that the mean free-driving speed in sharp curves was not negatively (and even perhaps somewhat positively) affected by ISA. Thus, no signs of compensatory behaviour or complacency were found for any of the systems.

The mean free-driving speed on lower limit sections on rural roads was reduced for all control and ISA conditions, compared to the speed on normal roads. The absolute reductions that were obtained in all conditions were about the same. From this it can be concluded that the lower speed limit does not affect the reduction in speed obtained by ISA, and again compensatory behaviour did not occur.

In both road environment scenarios (sharp curve, and lower limit section) where compensatory behaviour was likely to occur, it did not. However, this might be not sufficient to reject the hypothesis with respect to compensatory behaviour. Although the results with respect to car following, Time-to-collision and lane changes (not presented in this paper) did not show any significant difference between the three conditions for both experiments, they do suggest an increase of lane changes and a decrease for the time headway (Rook & Hogema, 2005). A larger number of measurements could have resulted in significant results. Furthermore it should be realised that in these experiments ISA was active during the complete ISA run. In the real world road environment it is plausible that ISA is only activated on certain road sections, thus allowing for compensatory behaviour on non-ISA sections (see for example van der Horst & Hogema, 1999).

Finally, for ISA in general, it should be realised that compensatory behaviour only becomes an issue when ISA has a subjective effect on speed behaviour. Furthermore, people need opportunities to compensate for the experienced delay.
Effects of ISA acceptance

With respect to acceptance, both experiments indicate that the usefulness of all four ISA systems is neutral to positive, with respect to satisfaction it is neutral to negative. The conclusion that low-force ISA is more accepted than high-force ISA is in line with the hypothesis that the closer to full ISA, the less accepted. The results with respect to the tactile gas pedal and the dead throttle are not in contradiction with this conclusion.

Further, the differences between both experiments with respect to usefulness and acceptance were too small to obtain any significant results. It can be concluded that low-force ISA is more accepted than high-force ISA, and it can be (at least) suggested that the tactile gas pedal is more accepted than the dead throttle. Comparing the results from both experiments, only a cautious suggestion can be made that the low-force ISA is more accepted than the tactile gas pedal and the dead throttle. This would be in line with the hypothesis: low-force ISA is most accepted, the tactile gas pedal a bit less, and the high-force ISA and dead throttle are least accepted. This is also in line with the results with respect to willingness to have. The conclusions with regard to acceptance are not founded statistically significant (with respect to the differences between ISA systems of experiment (a) and (b)) to determine a ranking order for all 4 systems in the right sequence on the scale from no ISA to full ISA.

This paper provides knowledge that policy makers can use to select an ISA system that best fulfils their policy needs when balancing public acceptance on the one hand and achieve safety effects on the other. It is not only the choice of HMI design that affects driving behaviour and public acceptance, but also the choice between voluntary and mandatory ISA.

ISA in the context of road systems design

As is concluded from this study, and many other studies: ISA works in a sense that it reduces speed, but dependent of the type of ISA it still allows for violations. Also concluded from this study: with respect to satisfaction, ISA is recognised by the drivers as useful, but doesn’t provide satisfaction. Generally it can be concluded that when the level of control of ISA changes from advisory ISA to full ISA: acceptance of ISA is lower; effect on driving behaviour increases (i.e. reduction of speed increases). This level of control can be changed by HMI design. The ultimate goal is a solution that keeps drivers from violating the speed limit, and at the same time has full acceptance of all road users. This ultimate solution is likely not easy to be attained by ISA alone as long as full ISA is not the way to go for drivers’ acceptance reasons. An important question is whether the acceptance that was measured in this study was about the ISA, or about the speed limit on the road they were driving on. For example, the sharp curve condition resulted in a speed choice irrespective of ISA, whereas the lower limit sections showed a combined effect of a lower speed limit and ISA on the driving speed. This suggest that when the speed limit is more in line with drivers’ expectancies on the proper speed given the road and traffic situation, the negative consequences for drivers’acceptance of ISA may become less too. The concept of Self-Explaining Roads (van der Horst & Kaptein, 1998) advocates a road environment where road users know how to behave simply on the basis of its design. Road characteristics are an important determinant of driving speed, and the whole set of road environments is an important determinant of the homogeneity of driving speed within road categories. Moreover, physical speed-reducing measures such as speed humps are becoming more and more a nuisance to road users. The same yields for a increasing use of speed cameras. For these situations, ISA (and even full ISA) could become a more acceptable alternative. To conclude, a really sustainable and safe solution may be that the use of intelligent electronic
systems such as ISA is combined and integrated in the whole design of the road traffic system consisting of both the geometric design and dynamic traffic management.

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