Improving speed behaviour: the potential of in-car speed assistance and speed limit credibility

N. Van Nes  M. Houtenbos  I. Van Schagen
Institute for Road Safety Research (SWOV), PO Box 1090, 2260 BB Leidschendam, The Netherlands
E-mail: Nicole.Van.Nes@swov.nl

Abstract: Speeding is still a common practice on many roads and it contributes to a significant number of crashes. Two new approaches to solve speeding issues are focused on: intelligent speed assistance systems (ISA) and speed limit credibility. Research has indicated that ISA is promising with respect to improving speed behaviour but has not been widely implemented yet. Another promising approach to reduce speeding involves adjusting the environment to improve the speed limit credibility. The aim here is to investigate the potential of both approaches and particularly the potential of the combination of these measures. A driving simulator study was conducted to investigate the individual and combined effects of the use of an ISA system and the speed limit credibility on drivers’ average speed and the amount of time spent speeding. The results indicated that both the informative ISA system used here and the speed limit credibility significantly improved speed behaviour. Drivers not using ISA appeared to be more susceptible to the speed limit credibility than those using ISA. It is concluded that both the measures can be effective to improve speed behaviour. The results obtained suggest that the properties of this particular informing and warning type of ISA could have resulted in the speed limit credibility neither affecting the amount of time speeding nor the average speed.

1 Introduction

1.1 Background

The faster one drives, the more likely it is that a crash will occur, and, in case of a crash, the more severe the injury consequences [1, 2]. Speeding (driving above the speed limit) is quite a common phenomenon in Europe and many other countries. Typically, 50% of drivers exceed the speed limit [3] and therefore a large safety benefit could be reaped from reducing driving speeds. There are a number of traditional and well-proved measures to improve speed limit compliance and reduce driving speeds, which consist of infrastructural measures and speed enforcement in particular. This study, however, focuses on two relatively new and promising measures to improve speed behaviour even further and continue reducing the number of speed-related crashes: the improvement of speed limit credibility and the implementation of in-car speed assistance systems.

A speed limit with high credibility implies that drivers consider that speed limit as logical or appropriate in the light of characteristics of the road and its immediate surroundings [4]. Concepts similar to speed limit credibility include ‘realistic’ speed limits [5] and ‘acceptable’ speed limits [6]. A speed limit can also have low credibility; this is the case when the speed limit is perceived as either too low or too high. Typically, when the speed limit lacks credibility, it is perceived as too low and people tend to drive faster than it. In the remainder of this paper, when referring to speed limits with low credibility, this typical credibility problem is meant. Previous research on speed limit credibility is quite limited and has included assessments of credibility based on static pictures rather than on dynamic environments [4]. In this paper, the potential of speed limit credibility is further explored in a dynamic setting.

The widespread implementation of in-car speed assistance systems, also called intelligent speed assistance (ISA), is
another quite promising measure to improve speed behaviour. A large range of ISA systems has been tested with different levels of intervention, ranging from open or informative systems (the driver is only informed about the speed limit), to closed or intervening systems (it is physically not possible to drive above the speed limit). It has been calculated, based on the known relationship between speed and both crash involvement and severity, that ISA should have a substantial effect on road safety. This effect is particularly expected of more intervening systems that make speeding physically impossible, in particular those based on dynamic speed limits [7]. Several ISA systems have been tested in various countries, in small and large field trials, generally with positive effects on average speed [8–11]. Less intervening systems, those only informing the driver about the current speed limit, tend to have less effect than more intervening systems [7].

Although ISA systems have proved to be quite effective with respect to improving speed behaviour, widespread implementation is not likely to take place in the short term [12]. Although it is important for policy makers to make an effort towards widespread implementation, they also have to think of other measures. Improving speed limit credibility is relatively new and has been mentioned as a promising means of improving speed behaviour [4]. Speed limit credibility can be enhanced by making adjustments to the environment, and it shows potential for short-term implementation. For policy makers, among others, it would be useful to gain insight into the expected effects of ISA and speed limit credibility separately and in relation to each other to determine when either measure or their combination would be more effective. Another relevant question is whether the short-term investment in infrastructural changes to improve speed limit credibility is still of value if ISA might become widely implemented at a later stage. The literature shows the effects or expected effects of each measure individually [4, 8, 11, 13–15], but no studies have focused on the combined effects.

Although ISA systems are already technically possible, they are still hardly being used on the road. One important issue that hinders the widespread implementation of ISA is public acceptance of the system. The system is often perceived as limiting the freedom of the driver. However, previous studies have shown that drivers participating in field trials often were sceptical in advance, but after they had experienced the system, their opinion tended to become (more) positive [8, 11, 16]. Apparently, the system is more convenient than people expect before using it.

1.2 Aim

This study aimed at investigating the potential positive effect of driving with an informative and warning ISA system and speed limit credibility on speed behaviour. Special interest is evinced in the combined effect of both measures, particularly whether they affect and, perhaps, even strengthen each other. As public acceptance seems to be a key factor in wide scale implementation of ISA, the satisfaction with the used ISA system was also briefly investigated. This study has focused on speed limit credibility of roads with an 80 km/h speed limit as it is a follow-up study of previous research on speed limit credibility [4].

The decision to use an informative and warning ISA variant in this study, rather than a more intervening type of ISA was founded on the expected ceiling effect of the use of a more intervening ISA system on speed behaviour. Also, the implementation of a warning ISA system integrated in a navigation device is closer to reality than a more intervening ISA system that physically prevents speeding. To explain the ceiling effect, a more intervening ISA system would allow less opportunity for the effects of speed limit credibility on speed behaviour. It would make speeding very hard or even physically impossible. As we are also interested in the effects of speed limit credibility on speed behaviour and the combined effects with ISA, it was necessary to use an ISA system with limited intervention to allow for all manipulations to have an effect on speed behaviour.

2 Method

2.1 Materials

The study was conducted in a fixed-based driving simulator. The simulator environment consisted of a network of seven rural roads with speed limits of 80 km/h. To create a more natural road network, some road sections with speed limits of 60 and 100 km/h were added. Only the roads with the 80 km/h limit were subject to this study and included in the data analysis.

The ISA system used in this experiment was integrated in a navigation device (Fig. 1) in the simulator mock-up.

![Figure 1 Illustration of ISA system used in this study](image-url)
The ISA system continuously provided visual information about the speed limit in force. When the driver exceeded the speed limit, the ISA system warned the driver visually (the speed limit indicator on the navigation device increased in size and started flashing) and verbally (a female voice said in Dutch: ‘you’re exceeding the speed limit. The speed limit is xx km/h’). Because of the different speed limits within the simulator environment (60/80/100 km/h), the ISA system indicated all different appropriate speed limits. This message was repeated every 10 s until the speed was reduced to below the speed limit. Exceeding the speed limit was defined as 1 km/h or more over the posted limit.

The level of satisfaction was measured by presenting four statements together with a five-point answering scale (completely disagree, disagree, neutral, agree and completely agree).

### 2.2 Design

This experiment followed a $2 \times 2$ mixed factorial design (Table 1), which included two independent variables. Speed limit credibility was included as a within-subjects factor ($N = 41$), and ISA as a between-subjects factor ($n_{ISA} = 20$; $n_{Non-ISA} = 21$).

Speed limit credibility was manipulated by varying a number of road characteristics that were identified in the literature as being relevant to speed behaviour [4, 17, 18], and that could easily be simulated in a driving simulator. For example, although road bendiness is considered as relevant to speed behaviour, it is hard to simulate it in a driving simulator as it increases the probability of simulator sickness occurring. The selected road characteristics that were eventually used to manipulate speed limit credibility were: (1) road width, (2) presence of vegetation near the road and (3) the type of separation between driving directions. For each road characteristic, a certain effect on speed behaviour can be expected: narrow roads, vegetation near the road and separation by lineation only were expected to induce lower speeds than wide roads, no vegetation and minor physical separation. Each road section had a different combination of characteristics and based on this, the road sections were categorised as likely to have a high or low speed limit credibility. A speed limit was categorised as having low credibility when the majority of the manipulated road characteristics were assumed to increase the intuitive speed. A speed limit was categorised as having high credibility when the characteristics that were assumed to increase speed and those that were assumed to decrease speed were balanced. Please note that a detailed discussion on the specific link between each road characteristic and speed limit credibility lies beyond the scope of this paper. The road characteristics were merely used to create road sections with either high or low speed limit credibility, which is the focus of this paper.

The pre-defined categorisation of speed limit credibility was validated within the experiment. All participants first drove the test route without revealing the speed limit. Participants were asked to drive at a reasonable speed, given the situation (i.e. their intuitive driving speed). A paired t-test revealed that on roads with an assumed high speed limit credibility, intuitive driving speeds did not differ significantly from the speed limit (mean difference = $-0.3$ km/h), whereas on roads with an assumed low speed limit credibility, a significant difference with the speed limit was indeed found ($t_{40} = 4.30$, $p < 0.001$; mean difference = 7.3 km/h). Thus, the behavioural data support the pre-determined categorisation.

The experimental route included seven road sections with a speed limit of 80 km/h, each 1500 m in length. Each participant encountered all the road sections in the same order. Three road sections were fitted out with road characteristics inducing high speed limit credibility and four road sections with road characteristics inducing low speed limit credibility.

### 2.3 Procedure

As mentioned above, all participants first drove the test route without revealing the speed limit to validate the pre-defined categorisation of speed limit credibility. Participants in the ISA condition were informed about the ISA system prior to driving with the system. They received an information leaflet about the ISA system in their navigation device, which would constantly indicate the current speed limit. The leaflet also indicated that changes in speed limit would be announced verbally and if they were to exceed the speed limit, this would be announced verbally as well. In addition, the current speed limit would be presented enlarged on the navigation device. Subsequently, participants were asked about their anticipated level of satisfaction with this particular system. The level of satisfaction experienced with the system was also assessed using the same set of statements, after the participant had driven with the system.

### 2.4 Participants

All participants, recruited from the panel of subjects of TNO, were invited to take part in the experiment by e-mail. Most of them had participated in a simulator study before. Participants received a compensation of travel costs and a modest financial incentive. All participants had a valid driver’s licence. In total, 41 people participated in the experiment. The sample included more men ($n = 33$) than women ($n = 8$). A possible bias resulting from this imbalance would affect each condition equally and is therefore not likely to be of relevance to the
general interpretation of the results. There was quite a good spread in age; young drivers – between 18 and 24 (n = 15), middle-aged drivers – between 25 and 50 (n = 11), and elderly drivers – between 51 and 65 (n = 15).

2.5 Data collection and analysis

The main focus in this study was on the effects of the two independent variables, ISA and speed limit credibility, on speed behaviour. To provide an indication of the effects on speed behaviour, two dependent variables were included: average driving speed and speeding time. The speeding time was defined as the percentage of time the participant spent on a road section while exceeding the speed limit by 10% or more, (i.e. 88 km/h or more on roads with the 80 km/h limit).

To be able to determine an effect of speed limit credibility, both variables were first computed for each road section separately and, subsequently, aggregated for each credibility condition. To avoid a confounding effect of acceleration and deceleration near intersections, the computed averages were based on the part of the road section from 100 m after an intersection up to 150 m before the next intersection.

The effects of the between-subjects factor (ISA) and the within-subjects factor (speed limit credibility) were analysed using the GLM ANOVA for repeated measures. Interaction effects were further explored using a simple effects analysis, which basically looks at the effect of one independent variable at individual levels of the other independent variable [19]. The difference between anticipated and experienced satisfaction was analysed using paired t-tests. For all analyses, a critical significance level of 5% was applied.

3 Results

An overview of the results for the mean driving speed and the speeding time can be found in Table 2.

3.1 Mean driving speed

Drivers in the ISA condition drove significantly slower than drivers without ISA ($F_{1,39} = 11.33; \ p < 0.01$; mean speed$_{ISA} = 78$ km/h against mean speed$_{Non-ISA} = 82$ km/h). The significant main effect of speed limit credibility indicated that participants drove significantly slower at road sections with high speed limit credibility than at road sections with low speed limit credibility ($F_{1,39} = 19.61; \ p < 0.001$).

The interaction effect between ISA and credibility on the mean driving speed was not significant, but a slight trend ($F_{1,39} = 2.92; \ p < 0.10$) indicated that non-ISA users could be more susceptible to high speed limit credibility than ISA users, (Fig. 2).

A simple main effects analysis was performed to further explore the nature of the indicated trend for an interaction effect [19]. The main effect of credibility for non-ISA users only indicates the effect of credibility is most relevant for the current situation on our roads where the use of ISA is not yet common practice. The simple main effects analysis showed that only for non-ISA users, the average driving speed was significantly lower at sections with high speed limit credibility than at sections with low speed limit credibility ($F_{1,39} = 18.38; \ p < 0.001$). For the ISA users, the effect of credibility was not significant, but a trend ($F_{1,39} = 3.79; \ p < 0.10$) indicated that ISA users could also tend to drive slower at sections with high speed limit credibility. Thus, the possible interaction effect as indicated

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Note: SLC, speed limit credibility; Effects in parentheses indicate trends (p < 0.10) rather than significant effects (p < 0.05)
by a slight trend is supported by the simple main effects analysis: the effect of credibility is significant for non-ISA users but not for ISA users.

### 3.2 Speeding time

ISA users spent significantly less time exceeding the speed limit than non-ISA users \((F_{1,39} = 10.76; p < 0.01)\). Also, participants spent significantly less time exceeding the speed limit at road sections with high speed limit credibility than at road sections with low speed limit credibility \((F_{1,39} = 12.41; p < 0.01)\).

A significant interaction effect between ISA and credibility on speeding time indicates that non-ISA users were more susceptible to high speed limit credibility than ISA users \((F_{1,39} = 5.72; p < 0.05)\), see Fig. 3. Again, looking separately at the effect of credibility for ISA users and non-ISA users in a simple main effects analysis, the effect of credibility was significant for the non-user group \((F_{1,39} = 17.08; p < 0.001)\), but it was not significant for the ISA users.

### 3.3 Satisfaction with the ISA system

Fig. 4 indicates that the anticipated satisfaction with the ISA system used in this study was fairly positive. A trend found in a paired t-test indicated that satisfaction with the ISA system, in general, could have a slight tendency to decrease after having experience with the system \((t_{20} = 2.087; p < 0.10)\). Experience with the system did not significantly affect the relatively positive level of satisfaction induced by providing visual information or visual warnings. In contrast, a paired t-test indicated that the voice warning was not appreciated \((t_{20} = 3.396; p < 0.001)\). The level of satisfaction even became negative after experience with the system.

### 4 Conclusions and discussion

#### 4.1 Improving speed behaviour using ISA or speed limit credibility

This study shows that both implementing ISA and improving speed limit credibility are promising measures to reduce speeding. The use of the informative and warning ISA system in this study resulted in lower mean speeds and less time spent speeding. These results confirm the findings of the large majority of studies that investigated the effect of ISA \([8, 11, 13–15]\), namely that an ISA system has the potential to reduce average driving speed to below the speed limit and to decrease the amount of time spent speeding. Furthermore, the results indicate that, overall, high speed limit credibility led to lower speeds and less time spent exceeding the speed limit than low speed limit credibility. Systematic research on the effects of speed limit credibility is still lacking, but these results confirm the assumptions made by other authors \([3, 5, 6, 20]\). Speed limit credibility is recognised as an important factor in speed behaviour and can substantially contribute to achieving lower speeds and less amount of time speeding. Speed behaviour improved more at road sections with high speed limit credibility than at road sections with low speed limit credibility.

#### 4.2 Improving speed behaviour using the combination of both measures

As speeding is such an important issue in improving road safety, it is not a matter of selecting a single measure, but more a matter of determining which combination of measures will achieve good results in the short term and in the long term. Therefore this study investigated a combination of two measures, ISA and speed limit credibility, and how they interact with each other.

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**Figure 3** Speeding time

**Figure 4** Anticipated and experienced satisfaction with the ISA system
Regarding the amount of time drivers speed, the effect of speed limit credibility was stronger for non-ISA users than for ISA users. Although not significant, the results for average speed pointed towards a similar effect. Looking separately at the effect of credibility on ISA and non-ISA users, it appeared that credibility had an effect on non-ISA users, but not on ISA users, for both average speed and the amount of time speeding. In conclusion, the results of this study suggest that, when driving with this particular informing and warning type of ISA, high speed limit credibility does not affect the amount of time people spend speeding nor their average speed.

When interpreting this outcome, it must be borne in mind that the ISA system used in this study was quite strict, with visual and verbal warnings at just 1 km/h and were repeated every 10 s. Furthermore, not only a visual but also a voice warning was given. It is possible that speed limit credibility has the potential to affect the driving speed of ISA drivers more if the system would be less intrusive (e.g. only informing, less frequent warnings, delayed warnings and so on). Further research is needed to explore this notion.

### 4.3 Satisfaction with the ISA system

As public acceptance is seen as a key factor to achieve wide scale implementation of ISA, the satisfaction with the used ISA system was investigated as well. The results show that participants had fairly positive expectations, although they became slightly less positive after having experienced the system. The voice warning was even judged negatively. However, most studies report that drivers become (more) enthusiastic about ISA once they have experienced it in practice [8, 11, 16, 21, 22]. An explanation of our finding may be that this particular ISA system was quite strict, with visual and verbal warnings at just 1 km/h or more over the limit and repeated every 10 s. This could particularly explain why the drivers disliked the verbal warning system. Previous studies [23] concluded that acceptance of an ISA system very much depends upon the specific feedback system. Acceptance of the current system may increase if the threshold for warnings would be higher and the warning frequency lower. Other studies on in-car assistance systems did indeed find that the less intervening systems are accepted better [8, 24]. At the same time, it was found that, for less intervening ISA systems, the effect on speed behaviour was smaller. Clearly, it is a matter of finding a balance between acceptance and effectiveness of the system. One possibility to increase acceptance is to allow users to customise the system to suit their own preferences concerning when and how to receive a warning or information.

### 4.4 Implications

This study investigated the combined effect of ISA and speed limit credibility, which was identified as a unique and highly relevant combination of measures to investigate. These days, ISA systems are rarely used in daily traffic. This study shows that, for drivers without ISA, improving speed limit credibility can be an effective measure to improve speed behaviour. In the future, when this particular ISA system would be widely implemented, no additional effect is expected from credibility. It is expected, however, that speed limit credibility will have more impact in combination with a less intrusive ISA system than the one in the current study.

In addition, speed limit credibility may have an effect on the acceptance of the ISA system: when speed limit credibility is high, the corrections/warnings are likely to be perceived as more reasonable and, hence, better accepted. In this study, no distinction was made between the acceptance of ISA at road sections with a credible speed limit and sections where the speed limit was less credible, however, it would be an interesting subject for future research.

Although the widespread use of the ISA system would be of major benefit to road safety, acceptance of ISA systems is still a hindering issue. A trade-off seems to exist between effectiveness and acceptance of the ISA system; the more intrusive the system, the larger the effect on speed behaviour but the lower the acceptance. One obvious direction for improvement is to focus on finding an optimum within the trade-off between effectiveness and acceptance. An alternative and promising approach would be not to accept this trade-off between effectiveness and acceptance, but to take up the challenge of establishing a win–win solution: the design of an ISA system which is both effective and pleasant to use, for example by developing a product design that can be customised and effective as well. Different people have different preferences and it is likely that individual acceptance of a system would be improved if the design allows drivers to choose their preferred settings in terms of how and when to warn or to provide information.

To further investigate the effect of speed limit credibility on speed behaviour, it would be interesting to systematically investigate its determinants. For preliminary studies, a simulator is ideal to manipulate the desired environments. However, it is important to be aware of the fact that speeding behaviour is related to many different factors that are hard to realise in a driving simulator study, such as time pressure, whether the driver expects to be punished for speeding, risk estimation and so on. Moreover, speed behaviour in driving simulators has been shown to be relatively rather than absolutely similar to speed behaviour in real traffic [25, 26]. For future research, it would be interesting to conduct similar studies in real

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**References:**

[8], [11], [16], [21], [22], [23], [24], [25], [26]
traffic in order to validate the results. The currently upcoming research method of naturalistic driving observation entails unobtrusive observation of the natural behaviour of drivers during their normal trips at the wheel of their own car. This research method is identified as a very promising observation method to gather reliable and accurate data on speed behaviour in real traffic [27–31].

As a next step, it would also be interesting to investigate another related measure: the implementation of dynamic speed limits. Dynamic speed limits are more flexible and offer the opportunity of being safer and more credible, as they can be adapted to the actual and local situation (e.g. weather and traffic), whereas the current static speed limits are not adaptive at all. It would be interesting to investigate the effect of dynamic speed limits on speed behaviour while taking speed limit credibility into account.

5 References


