Intelligent speed adaptation—Effects and acceptance by young inexperienced drivers

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A B S T R A C T

This study assessed the relative effects of two intelligent speed adaptation (ISA) systems (informative and actively supporting) on simulated driving performance and acceptability in a sample of inexperienced and experienced drivers. Participants drove a series of simulated drives under three conditions: no ISA (control), ISA informative and ISA actively supporting. The informative system significantly reduced speed and was particularly effective in reducing top-end speeds. Comparable reductions were not found for the actively supporting system. Differences in the effectiveness and acceptability of ISA systems were noted across experienced and inexperienced drivers. The ISA systems appeared more effective at reducing speeds for experienced drivers on some road types. Experienced drivers’ subjective satisfaction ratings of the systems also remained constant over the trial, whereas the inexperienced drivers’ ratings changed after experience. There was little evidence that drivers engaged in negative behavioral adaptation and no evidence that subjective workload levels increased with ISA use. Future directions for examining the safety benefits of ISA, particularly for inexperienced drivers, are discussed.

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1. Introduction

Speeding constitutes a significant road safety problem worldwide. The relationship between speed and crash risk and severity is well established in the traffic safety literature (see Aarts and van Schagen, 2006; Nilsson, 2004). In Australia alone, excessive or inappropriate speeds are estimated to be an important contributing factor in around one quarter of fatal road crashes (Diamantopoulou et al., 2003).

There are many and varied reasons why drivers speed. For many, speeding is unintentional, brought about by a lack of awareness of the current speed limit and/or vehicle speed, or simply because it is a habitual behavior. For others, speeding is intentional; drivers speed for the thrill of it, because of peer-pressure, or because it holds some value, such as saving time (Rothengatter, 1991). A range of measures have been developed to manage excessive speed. Traditional measures include those aimed at drivers (e.g., police and automated enforcement and advertising campaigns) and engineering measures in the road environment (e.g., reduced speed limits around schools, perceptual speed countermeasures, speed humps, street narrowing). These measures, however, are only partly effective in bringing about large and sustained speed reductions (e.g., Holland and Conner, 1996; Mountain et al., 2005). A newer and promising measure to reduce excessive speeds and speed-related crashes is the use of advanced driver assistance systems (ADAS), particularly intelligent speed adaptation (ISA).

ISA is a generic term for a class of ADAS in which the driver is warned and/or vehicle speed is automatically limited when the driver is, intentionally or inadvertently, traveling over the posted speed limit, or some other pre-defined speed threshold. ISA systems establish the location of the vehicle, compare the current speed of the vehicle with the local posted speed limit and issue the driver with visual, auditory and/or tactile warnings, or limit vehicle speed, if the vehicle exceeds the posted limit.

There are various classes of ISA, which differ according to the level of support they provide, and the degree to which they are sensitive to real-time changes in posted speed limits (e.g., around schools; near accident scenes) and to changes in driving conditions (e.g., bad weather; icy roads) which may warrant variable speed limits. Informative (alerting) ISA provides the driver with auditory and/or visual warnings if they exceed the posted speed limit beyond a specified threshold (e.g., by 1 or 2 km/h). Actively supporting ISA provides the driver with a tactile warning, usually in the form of increased upward pressure through the accelerator pedal, if the posted speed limit, or some other pre-defined speed threshold, is exceeded (Regan et al., 2006). This is sometimes accompanied by visual and/or auditory warnings or information (e.g., Várhelyi et
ISA limiting devices make it impossible for the driver to exceed the posted limit (or some other pre-determined speed threshold) by automatically limiting the speed of the vehicle to the posted speed limit using speed governors and speed retarders. The focus of the current study is on ISA informative and actively supporting systems.

A wide body of research has examined the potential safety benefits of ISA technologies and their influence, both positive and negative, on driving performance (Adell and Várhelyi, 2008; Agerholm et al., 2008; Arhin et al., 2007; Broekhuis and de Waard, 1999; Carsten et al., 2008; Comte and Jamson, 2000; Hjamlåd and Várhelyi, 2004; Regan et al., 2006; Várhelyi et al., 2004; Vlassenroot et al., 2007; Warner and Aberg, 2008). This research has generally found that ISA systems, and particularly the more controlling variants of ISA, are effective at reducing speed, speed variability and speed violations, and reducing injury and fatal crashes. Like most of the advanced driving assistance system (ADAS) literature, however, much of the ISA research has focused on middle-aged, experienced drivers. The possible benefits and risks of in-vehicle support systems for young drivers have been hypothesized in the literature (e.g., Brovold et al., 2007; Lee, 2007; Gregersen and Falkmer, 2003), yet very little actual research has examined the impact of ADAS in general, or ISA specifically, on young inexperienced drivers’ behavior and acceptance. Moreover, what work has been done has included as young drivers, age groups (e.g., aged 24 years and over) that prohibit conclusions being drawn about the youngest, most novice drivers (Adell and Várhelyi, 2008; de Waard et al., 1999; Comte, 1996).

ADAS, including ISA, have substantial potential to improve the safety of young novice drivers (Lee, 2007). ISA has the potential to improve vehicle control for inexperienced drivers, for example, by providing them with continuous feedback on when and where they are speeding and, in the case of limiting systems, supporting the driver to control the vehicle to limit speed. ISA also has potential to improve inexperienced drivers’ ability to perceive hazards. By reducing their speed, ISA can provide drivers with more time to identify and respond to hazards; and by reducing the need to actively monitor both the speedometer and external speed signs, it has potential to free up attentional capacity which can be used to respond to unexpected events. Feedback provided by ISA (especially by systems sensitive to transient changes in ambient driving conditions) may help young drivers to become better calibrated in selecting appropriate driving speeds for prevailing conditions (e.g., on icy or wet roads). The warnings issued by ISA may even act to moderate peer influences, by repeatedly challenging the driver and passengers in situations where increases in speed derive from peer-pressure.

Despite the potential safety benefits, ISA may have some unintended consequences for young inexperienced drivers. It is widely recognized that inexperienced drivers lack the driving skills necessary to operate a vehicle using only minimal attentional resources and, therefore, often lack the spare capacity to attend to additional tasks such as monitoring system information and warnings (Lee, 2007). Unless ISA systems are designed to meet the specific needs of inexperienced drivers, it may be more difficult for them to divide their attention appropriately between the driving task and the information presented by the ISA system, potentially undermining safety. ISA systems also automate some aspects of the driving task, reducing drivers’ need to actively monitor external speed signs and the speedometer. Such automation could potentially lead to driver under-load and a loss of situation awareness, making drivers less responsive to hazardous events (Walker et al., 2006), or, alternatively, amplify drivers’ over-confidence in their driving ability (Lee, 2007). Driver over-reliance on ISA is also of concern if the system fails or issues false information, if drivers use vehicles not equipped with ISA, or if drivers fail to adopt slower speeds when conditions warrant it. Young inexperienced drivers may be more vulnerable to these unintended side-effects of ISA.

Finally, young novice drivers have a greater propensity to adopt risky driving styles than more experienced drivers (Hatfield and Fernandez, 2009) and, thus, may be less likely to accept ISA and deliberately ignore the speed warnings issued by the system, particularly if they view the system as a monitor rather than as a form of guidance (Lee, 2007). Indeed, research has found that younger drivers (23–35 years) tend to hold more negative attitudes towards ISA than their older counterparts (Comte, 1996). Young et al. (2004) also found that young novice drivers (17–25 years) rated more intrusive technologies, such as collision warning devices and ISA, as less acceptable than relatively unobtrusive devices such as seatbelt reminder systems.

In order to better tailor ISA to meet the specific needs of young inexperienced drivers, it is necessary to examine whether and how different variants of ISA, which vary in their level of support and intrusiveness, affect the behavior (both positive and negative) and acceptability ratings of this driver group. It is possible, for example, that actively supporting ISA may be more effective for young inexperienced drivers than informative ISA given the greater level of support provided, but may be deemed less acceptable given its greater intrusiveness.

1.1. Aims of the current study

Of primary interest in the present study is whether and how two ISA systems (informative and actively supporting) affect the simulated driving performance and acceptance of young inexperienced drivers, and whether these effects differ from those found with an older, more experienced sample.

2. Method

2.1. Participants

A total of 15 young inexperienced drivers (7 male and 8 female) and 15 experienced drivers (10 male and 5 female) completed the study. The mean age of the inexperienced and experienced drivers was 20.3 years (SD = 2.4) and 38.4 years (SD = 6.1), respectively. The mean amount of accumulated driving experience for the young inexperienced drivers was 5.5 months (SD = 2.6) and 19.3 years (SD = 6.8) for experienced drivers.

Participants were recruited using advertisements placed in Monash University newsletters. Selection was made on the basis that each participant had not had their license suspended or revoked, had no history of motion sickness, epilepsy or hearing impairment and fell within one of two selection categories: young inexperienced drivers aged 18–24 years who had held a driver’s license for at least 10 months; and experienced drivers aged 30–50 years who had held a driving license for at least 5 years.

2.2. Intelligent speed adaptation systems

Two variants of ISA were evaluated. The informative ISA system (ISA-I) provided drivers with a combination of auditory and visual warnings if the posted speed limit was exceeded by 2 km/h or more. The warning sequence comprised two stages. When the driver first exceeded the posted speed limit by 2 km/h or more, a static visual icon in the form of a miniature speed limit sign appeared on a visual display located on the dashboard to the left of the driver. This static visual warning was accompanied by a short duration auditory tone (beep). If the driver continued to exceed the speed limit by 2 km/h or more for two or more seconds the visual icon flashed and a repetitive auditory tone was issued.
The actively supporting system (ISA-A) was functionally identical to the actively supporting system evaluated in the Australian “TAC SafeCar” Field Operational Test (Regan et al., 2006). It provided the driver with a two-stage warning sequence if the posted speed limit was exceeded by 2 km/h or more. Stage 1 and the onset of the stage 2 warning was identical to the ISA-I system. However, in the ISA-A stage 2, rather than issuing an auditory tone, the driver received upward pressure on the accelerator pedal. Drivers were able to override this resistance in the accelerator via a “kick down” function.

2.3. MUARC driving simulator

The experiment was carried out in the Advanced Driving Simulator located at the Monash University Accident Research Centre (MUARC). Scenarios were generated by a Silicon Graphics Onyx computer and projected by three BARCO 700 HQ projectors onto a front display screen that subtended a visual angle of 180° horizontally and 40° vertically. The scenarios were displayed with a refresh rate of 30 Hz and a resolution of 1280 × 1024 pixel (front panel) and 640 × 480 pixel (front side panels). A Crystal River Engineering Audio Reality Accoustetron II audio system produced accurate localized sound such as engine and road noises and sound from other vehicles. Drivers viewed the scenarios while seated in a 1993 ED Ford Falcon Sedan that was positioned on a motion platform that displaced the vehicle according to the virtual dynamics of the car and environment (see Fig. 1).

2.4. Simulated driving scenarios

The simulated drives consisted of a familiarization drive, a practice drive and nine test-drives. The test-drives comprised three blocks of three drives. For one block of drives, the ISA system was disengaged (no ISA). The ISA-I and ISA-A systems were engaged successively for the other two blocks of drives. Each of the three blocks of drives comprised different driving environments: arterial, residential and rural environments, each with two or three speed zones. The drivers drove each driving environment under each of the ISA conditions (no ISA, ISA-I and ISA-A). The driving environments were comparable but not identical across the three blocks of drives to avoid learning effects. The order in which drivers experienced the ISA conditions and driving environments was partially counterbalanced to avoid practice effects.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Arterial</th>
<th>Residential</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap acceptance task</td>
<td>• Gap acceptance task</td>
<td>• Two yielding events—participants had to stop and give way to one motorcycle and two cars at each intersection</td>
<td>Car following task</td>
</tr>
<tr>
<td>Car following task</td>
<td>• Car following task</td>
<td>• Car following task</td>
<td>Car following task</td>
</tr>
<tr>
<td>Yielding to pedestrian on crossing</td>
<td>• Yielding to pedestrian on crossing</td>
<td>• Gap acceptance task</td>
<td></td>
</tr>
<tr>
<td>Vehicle emerged suddenly from the right into participant’s lane of travel</td>
<td>• Vehicle emerged suddenly from the right into participant’s lane of travel</td>
<td>• None</td>
<td>• Car emerged suddenly from left side street into participants’ lane of travel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Critical events</th>
<th>Arterial</th>
<th>Residential</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed zones (length)</td>
<td>60–2.5 km⁴</td>
<td>40–0.5 km</td>
<td>50–2.5 km</td>
</tr>
<tr>
<td>70–3.5 km</td>
<td>50–5.0 km</td>
<td>60–2.0 km</td>
<td></td>
</tr>
<tr>
<td>80–1.5 km</td>
<td>60–0.5 km</td>
<td>80–2.5 km</td>
<td></td>
</tr>
</tbody>
</table>

All speed zone lengths are approximate values.

The arterial, residential and rural environments ranged between 6 and 7 km in length and contained a number of tasks (e.g., gap selection) and critical events that required rapid braking to avoid a collision. Table 1 displays the events contained in each environment.

2.5. Design and statistical analysis

A 3-way (2 × 3 × 8) mixed design was used with age/driving experience (between subjects: experienced versus inexperienced), ISA condition (within-subjects; ISA-I, ISA-A and no ISA), and driving environment (within-subjects; arterial 60, 70 and 80 km/h, residential 40, 50 and 60 km/h and rural 60 and 80 km/h). The dependent variables examined in the study are listed in Table 2. All analyses were performed using SPSS version 15.0.

The three speed-related variables in Tables 3–5, proportion of driving spent above the speed limit, mean speed and maximum speed, were analyzed through application of a generalized estimating equation (GEE) (Hardin and Hilbe, 2003) to the 2 × 3 × 8 analysis design. Responses for each of the three speed measures followed an approximate normal distribution so the GEE was specified with normal error function and identity link while the inter-correlation between the repeated measures was specified as unstructured.

Two forms of the GEE were used in the analysis. The first estimated the main effects of ISA type, driving experience as well as their interaction within each driving environment. The form of the
The yielding, following distance, reaction to critical events, workload and acceptability data were analyzed using mixed model ANOVA, using the Greenhouse–Geisser correction where the sphericity assumption was violated.

2.6. Procedure

Participants completed two separate testing sessions, each lasting approximately 1.5 h. In the first session participants were given information about the experiment, performed a familiarization and practice drive in the simulator, and completed the first block of three test-drives. In the second session participants completed the remaining two blocks of six test-drives. Participants were instructed to drive as they would normally and obey the road rules.

Before and after completing each of the three blocks of test-drives, participants completed the NASA-RTLX (Byers et al., 1989). Participants also completed the acceptability scale developed by Van der Laan et al. (1997) before and after completing the two drive blocks in which the ISA systems were active. The before exposure acceptability measurements were collected after participants had received information about the function and purpose of the ISA systems, but before they had interacted with them.

3. Results

3.1. Effects on speed

The effects of the ISA systems on free-flow speeds (i.e., where speed was unobstructed by other vehicles) were examined, first across all road types combined to establish the overall effect of ISA (using GEE Eq. (2)) and then for road types individually to determine any differential effects of ISA across driving environments (using GEE Eq. (1)). The results for individual road types have been included to demonstrate that ISA can have a different impact on driver groups and road types; however, these results should be interpreted with care given a lack of statistical power.

The GEE model of Eq. (2) was fitted to examine the proportion of time spent exceeding the speed limit across all road types. A model was fitted with the experience level \( x \) ISA condition interaction included. This interaction was not significant, thus it was dropped from the model. No main effect for experience level was

\[
x_{ijk} = \alpha_k + \beta_{ik} + \gamma_{jk} + \delta_{ijk}
\]

Table 3

Proportion of driving time spent exceeding the speed limit (95% confidence interval) across ISA conditions and road type for experienced and inexperienced drivers.

<table>
<thead>
<tr>
<th>Road type (km/h)</th>
<th>No ISA (%)</th>
<th>ISA-I (%)</th>
<th>ISA-A (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial (60)</td>
<td>Experienced 28.7 (18.0–39.3)</td>
<td>17.6 (10.8–24.5)</td>
<td>28.6 (17.4–39.7)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 32.0 (21.1–42.9)</td>
<td>21.7 (14.8–28.7)</td>
<td>24.7 (15.2–34.3)</td>
</tr>
<tr>
<td>Arterial (70)</td>
<td>Experienced 5.8 (2.0–9.6)</td>
<td>3.4 (1.7–5.1)</td>
<td>5.5 (2.1–8.9)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 5.4 (1.6–9.2)</td>
<td>5.2 (2.2–8.2)</td>
<td>11.1 (5.9–16.4)</td>
</tr>
<tr>
<td>Arterial (80)</td>
<td>Experienced 4.9 (0.5–9.4)</td>
<td>3.4 (0.8–5.9)</td>
<td>8.6 (2.9–14.3)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 4.9 (0–10.6)</td>
<td>5.1 (2.2–7.9)</td>
<td>11.9 (4.5–19.4)</td>
</tr>
<tr>
<td>Residential (40)</td>
<td>Experienced 58.1 (48.8–67.3)</td>
<td>55.2 (49.1–61.3)</td>
<td>55.7 (49.6–61.9)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 59.9 (50.8–69.0)</td>
<td>56.3 (50.1–62.4)</td>
<td>62.2 (51.6–72.8)</td>
</tr>
<tr>
<td>Residential (50)</td>
<td>Experienced 25.9 (10.9–40.8)</td>
<td>11.2 (6.8–15.1)</td>
<td>20.5 (8.5–32.6)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 20.4 (12.4–28.3)</td>
<td>12.1 (7.0–17.1)</td>
<td>24.5 (14.2–34.7)</td>
</tr>
<tr>
<td>Residential (60)</td>
<td>Experienced 19.3 (4.5–34.2)</td>
<td>1.2 (0–2.8)</td>
<td>2.6 (0–6.0)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 10.2 (2.9–18.5)</td>
<td>8.2 (1.9–14.5)</td>
<td>3.3 (0–6.9)</td>
</tr>
<tr>
<td>Rural (60)</td>
<td>Experienced 21.6 (6.7–36.4)</td>
<td>6.6 (2.1–10.9)</td>
<td>16.7 (8.8–24.6)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 9.3 (4.5–14.3)</td>
<td>8.5 (5.7–11.3)</td>
<td>10.1 (5.8–14.3)</td>
</tr>
<tr>
<td>Rural (80)</td>
<td>Experienced 11.3 (5.3–17.2)</td>
<td>9.5 (1.7–17.2)</td>
<td>12.4 (4.5–20.2)</td>
</tr>
<tr>
<td></td>
<td>Inexperienced 11.2 (3.9–18.5)</td>
<td>5.9 (1.8–10.1)</td>
<td>9.4 (4.1–14.7)</td>
</tr>
</tbody>
</table>

Average ISA effect relative to no ISA over all road types

Reference -8.4 (-13.3, -3.6) -3.1 (-6.4, 0.2)

Note: No ISA – control; ISA-I – ISA-informative; ISA-A – ISA-actively supporting.

The 50 km/h rural zone was not examined in the free-flow speed analyses, as it contained a car following task.

The yielding, following distance, reaction to critical events, workload and acceptability data were analyzed using mixed model ANOVA, using the Greenhouse–Geisser correction where the sphericity assumption was violated.

3. Results

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The GEE model of Eq. (2) was fitted to examine the proportion of time spent exceeding the speed limit across all road types. A model was fitted with the experience level \( x \) ISA condition interaction included. This interaction was not significant, thus it was dropped from the model. No main effect for experience level was

\[
x_{ijk} = \alpha_k + \beta_{ik} + \gamma_{jk} + \delta_{ijk}
\]
found. However, as shown in Table 3, across all road types, the proportion of driving time spent exceeding the speed limit reduced significantly by just over 8% with use of the ISA-I system \((p < .001)\), but did not reduce significantly with use of ISA-A \((-0.3\%, p = 0.07)\). The two ISA systems did not differ significantly from each other as reflected in the overlapping confidence limits on each estimate (taken from the models fitted) at the bottom of Table 3.

Across individual road types, the percentage of time spent speeding reduced significantly from no ISA levels in the arterial 60 km/h and residential 50 and 60 km/h zones when using ISA-I \((p < .020)\). In addition, the percentage of time spent speeding was significantly lower when using ISA-I compared to ISA-A in the arterial 60 km/h and residential 50 and 60 km/h zones \((p < .040)\). Use of ISA-A significantly reduced the proportion of driving time spent speeding in residential 60 km/h zones only \((p = .007)\).

A significant ISA condition by experience level interaction was also revealed in the rural 60 km/h zone \((p < .020)\). The pattern of means suggest (Fig. 2) that for the experienced drivers, use of both ISA systems reduced the proportion of time spent speeding, while for the inexperienced drivers, only ISA-I reduced excessive speeds, and the time spent speeding increased slightly for this group with use of ISA-A. This interaction should be interpreted with caution, however, as none of the individual main effects were significant.

The effects of ISA on mean and maximum free-flow speeds were also examined. Table 4 displays mean speed across ISA conditions, experience levels and road types. For all road type combined, no ISA condition \(\times\) experience level interaction, nor a main effect for experience, was found. ISA condition did, however, have a significant effect on mean speed, whereby mean speed reduced significantly \((by 1.0 \text{ km/h})\) with use of the ISA-I system \((p = .011)\), but not with use of ISA-A \((-0.3 \text{ km/h}, p = 0.379)\).

When examining mean speed for road types individually, a significant ISA condition by experience level interaction was found in rural 60 km/h \((p < .002)\) and arterial 70 km/h speed zones \((p = .037)\). In the rural 60 km/h zone, inexperienced drivers’ mean speeds did not differ across ISA conditions; however, experienced drivers’ mean speed reduced significantly when the ISA-I system was active compared to when no ISA or ISA-A was active. In arterial 70 km/h zones, the inexperienced drivers had significantly higher mean speeds than experienced drivers, but only when using the ISA-A system. Mean speed did not differ across the two groups in the no ISA or ISA-I conditions for this speed zone. Across groups, significant reductions in mean speed were also found in the arterial 60 km/h \((p = .015)\) and rural 60 \((p < .001)\) and 80 km/h zones \((p = .035)\) with use of ISA-I. While there was a trend for mean speed to reduce in other speed zones with the use of ISA, these reductions were not significant.

Table 5 displays the maximum speeds across ISA conditions, experience levels and road types. Similar to mean speed, for all roads combined, no ISA condition \(\times\) experience level interaction, nor a main effect for experience, was found for maximum speeds. ISA did, however, have a significant effect on maximum speed, with maximum speed reducing significantly \((by 1.5 \text{ km/h})\) when the ISA-I system was active \((p = .001)\), but not when ISA-A was active \((-0.8 \text{ km/h}, p = 0.170)\).

When looking at maximum speed for individual road types, a significant ISA condition by experience level interaction was revealed in rural 60 km/h speed zones \((p < .013)\). Here the pattern of means indicate that while inexperienced drivers’ maximum speeds did not differ across ISA conditions, the experienced drivers’ maximum speeds reduced by 4.4 km/h with ISA-I and by 2.5 km/h with ISA-A active, compared with no ISA. The maximum speeds reached by both driver groups also reduced with use of ISA in arterial 60,
residential 50 and rural 80 km/h zones \((p < .005)\). Drivers’ maximum speeds reduced by 4 km/h in the residential 50 km/h zone and by over 3 km/h in the rural 80 km/h zones with ISA-I. In the arterial 60 km/h speed zone, maximum speeds reduced by 2 km/h with ISA-I active and by 2.3 km/h with use of ISA-A.

### 3.2. Yielding behavior

Approach speeds and yielding behavior were examined at two intersections in the residential drive, where participants were required to give way to a motorcycle and two cars traveling along an intersecting road. Both yielding events were identical. Two, 3-way mixed ANOVAs were conducted to examine speed at the point at which the first vehicle (motorcycle) was discernable and speed when entering the intersection.

For speeds at which the first intersecting vehicle was discernable, significant main effects were found for ISA condition \((F(2,56) = 5.80, p = .008)\), driving experience level \((F(1,28) = 4.62, p = .040)\) and yield event \((F(1,28) = 8.96, p = .006)\). The inexperienced drivers were traveling significantly faster (2.5 km/h) than the experienced drivers when the first intersecting vehicle was discernable. All drivers were traveling significantly faster (1 km/h) at this point in the second yielding event, and all drivers were traveling significantly faster at this point with ISA-A, compared to the ISA-I and no ISA conditions \((p < .05)\).

Significant main effects for driving experience level \((F(1, 28) = 4.62, p = .04)\) and yield event \((F(1,28) = 8.96, p = .006)\) were also found for intersection entry speeds. Again, inexperienced drivers were traveling significantly faster (2.1 km/h) than experienced drivers when entering the intersection, and all drivers were traveling significantly faster (11.2 km/h) at this point in the second yielding event. No significant differences were found across ISA conditions for intersection entry speeds.

### 3.3. Following behavior

All three drives included a car following task, where drivers were required to follow a lead vehicle that was traveling 15 km/h lower than the speed limit. One, 3-way mixed ANOVA was conducted on the car following data to examine differences in mean time headway across experience levels, ISA condition and driving scenario. The results revealed a significant experience level by drive scenario interaction \((F(2,56) = 9.29, p < .001)\), whereby the inexperienced drivers maintained significantly shorter mean time headways during the car following task in the arterial \((F(2.9) \sim 2.16, p = .048)\) and rural drives \((2.9 s; F(14) = 3.57, p = .003)\), compared to the experienced drivers \((3.4 \text{ and } 5.1 s, \text{ respectively})\.

No significant differences in mean time headway were found across ISA conditions.

### 3.4. Reaction time to critical events

To examine the possible effects of ISA on reactions to hazardous events, drivers’ brake reaction times to three critical events involving other vehicles were examined across the three ISA conditions for experienced and inexperienced drivers. Drivers encountered three critical events, one in the arterial drive and two in the rural drive, each involving another vehicle pulling out unexpectedly onto the roadway in front of them. In all events, the intruding vehicles were close enough to the participants’ car to require rapid, heavy braking to avoid a collision. Time to initiate braking from the point at which the intruding vehicles first entered the roadway was examined in three 2-way mixed ANOVAs; one for each critical event.

No significant differences in brake reaction time were found across ISA conditions. However, inexperienced drivers took significantly longer (1.1 s) than the experienced to brake in response to the vehicle unexpectedly entering the roadway in the arterial event \((F(1,28) = 8.09, p = .011)\).

### 3.5. Acceptability and subjective workload

Driver workload was assessed using the NASA-RTLX, while acceptability of the ISA systems was examined using Van der Laan et al.’s (1997) acceptability scale. Scores on the six sub-scales of the NASA-RTLX were averaged to obtain an overall measure of subjective workload for each ISA condition. No significant differences in workload were found between the ISA conditions or driving experience levels, indicating that the use of the ISA systems did not increase or decrease self-reported workload for either driver group.

The nine items comprising the Van der Laan et al.’s (1997) acceptability scale were combined to form two sub-scales: Usefulness and Satisfying. These sub-scales were analyzed separately to examine...
differences in acceptability ratings across ISA conditions and experience levels before and after exposure. Fig. 3 plots the pre- and post-exposure acceptability scores for the Usefulness and Satisfying sub-scales across ISA conditions and driving experience levels.

A significant interaction between ISA condition and exposure (pre and post) was found for Usefulness (F(1,28) = 7.39, p = .011). Usefulness ratings for ISA-I did not differ significantly between pre- and post-exposure; however, there was a significant difference in the Usefulness ratings of ISA-A between pre- and post-exposure, with the drivers rating this system less useful after experiencing it (t(29) = 2.11, p = .044).

For the Satisfying sub-scale, a significant 3-way interaction between ISA condition, driving experience level and exposure (pre and post) was revealed (F(1,28) = 9.69, p = .004). Simple interaction effects revealed a significant 2-way interaction between ISA condition and experience level on the Satisfying sub-scale pre-exposure (R(1,28) = 5.16, p = .031). However, there was no significant interaction between ISA condition and experience level on the Satisfying sub-scale post-exposure. As displayed in Fig. 3, experienced drivers rated ISA-A as more satisfying than ISA-I both before and after exposure to the systems. In contrast, prior to exposure, the inexperienced drivers rated ISA-I as more satisfying than ISA-A. However, after experiencing the systems, inexperienced drivers changed their initial assessment, rating the actively supporting variant as more satisfying.

4. Discussion

The aim of the current study was two-fold: to examine the relative effects of informative and actively supporting ISA systems in terms of speeding behavior, behavioral adaptation and driver acceptability; and to explore whether the effects of these two systems differed across experienced and inexperienced drivers.

This study is the first one known to systematically examine whether and how ISA differentially affects the driving performance and acceptability of young, inexperienced drivers versus experienced drivers. The results revealed only limited differences between the experienced and inexperienced drivers in terms of the impact of the ISA systems on driving performance. Specifically, the ISA systems appeared to be more effective at reducing speeds for the experienced drivers on some road types and, in one instance, the inexperienced drivers’ speeds even increased with use of the ISA-A system. This result is not surprising given that young drivers in general have a propensity to speed (Gregersen and Falkmer, 2003) and alerting ISA systems have been found to be less effective among those who intentionally exceed the speed limit (Hjämlidahl, 2005; Jamson, 2006).

Small differences were also observed between the inexperienced and experienced drivers in terms of the acceptability of the ISA systems. Inexperienced drivers initially reported that ISA-A would be less satisfying than the ISA-I system, but changed their mind after exposure, suggesting that ISA-A was actually more satisfying than the ISA-I system. Experienced drivers, in contrast, rated the ISA-A system as more satisfying both before and after exposure. Overall, the differences observed between the two driver groups were few and small and it is difficult to draw conclusions about whether ISA is more or less effective or acceptable for one group over the other, or whether the different variants had different success rates among the two groups. Even so, there was some evidence for a differential effect of ISA on drivers of different ages and experience levels and this should be examined further. For instance, it may be the case that in an on-road context, where workload levels and safety consequences are greater and exposure to ISA is greater, differential effects of ISA for experienced and inexperienced drivers become apparent.

Across groups and road types, use of the ISA-I system reduced mean and maximum speeds and encouraged drivers to spend less time exceeding the speed limit. The ISA-A did not, however, have any significant speed reduction effects. The ISA-I system was particularly effective in reducing higher end speeds (maximum and excessive speeds), rather than producing large reductions in average speed. These findings are generally consistent with the results of previous on-road and simulator studies examining ISA alerting systems, which have found mean speed reductions of between 1 to 8 km/h on certain road types, but much larger reductions in maximum and 85th percentile speeds and the time spent exceeding the speed limit when using ISA (Adell et al., 2008; Regan et al., 2006; Várhelvi et al., 2004; Vlassenroot et al., 2007). One explanation for this finding is that, while drivers reduce their top speeds and the amount of time exceeding the speed limit, they also increase their lower-end speeds to either compensate for the reduction in top speed or because they are using the ISA as a form of cruise control.

It is unclear why ISA-I was more effective than the ISA-A system in reducing speeds in the current study. The result is not in-line with research on other driver support systems, which have found that tactile warnings are more effective in assisting drivers to avoid rear-end collisions than auditory warnings (Mohabbi et al., 2009; Scott, 2008). This finding is in contrast with Adell et al.’s (2008) on-road trial, the only other known study to have systematically examined the relative effects of ISA informative and actively supporting systems. Adell et al. found that their actively supporting system was more effective at reducing speeds than an informative ‘beep’ system. The inconsistencies between the studies could result from the different methodologies used (simulator versus on-road) and/or the different length of time that drivers were exposed to the systems in each study (30 min versus 1 month). An alternative explanation why ISA-I was more effective than the ISA-A system in the current study is that the warnings issued by the informative system may have been more aggressive (i.e., louder and more persistent) than both the beep system used by Adell et al. and the tactile warnings issued by the actively supporting system. Thus, the ISA-I system may have been more likely to attract attention or might have been harder to ignore, either of which would be likely to induce a response.

Although the current drivers encountered a total of eight different road scenarios, significant decreases in speed were not found for all road types. While it is difficult to draw firm conclusions about the exact nature of the relationship between road type and ISA effectiveness, a general trend was that significant effects of ISA were mainly found for road types on which higher speeds may be perceived as safer or more possible (e.g., rural and arterial roads) and
The possibility of negative behavioral adaptation is always of concern when introducing new technologies into the vehicle, particularly for young, inexperienced drivers. Behavioral adaptation has been defined by the OECD (1990) as “those behaviors which may occur following the introduction of changes to the road–vehicle–user system and which were not intended by the initiators of the change”. In the case of ISA, within the scenarios explored in this study, behavioral adaptation may have occurred if drivers traveled at higher speeds in certain situations (e.g., approaching intersections), failed to yield to other road users, in order to compensate for reduced speeds elsewhere, or if driving became automated because of over-reliance on the system. For either group, there was little evidence of negative behavioral adaptation in terms of yielding to other vehicles, approach speeds at intersections, and car following behavior. There was also no evidence that drivers took longer to react to the critical events when ISA was active, suggesting that use of ISA, by either inexperienced or experienced drivers, did not result in a loss of vigilance.

The drivers’ experiences with the ISA systems in terms of subjective workload and acceptance were elicited using questionnaires. There was no evidence that subjective workload levels increased when using either of the ISA systems. Acceptability ratings after use of the ISA systems revealed that the ISA-I system was deemed more useful than ISA-A. These ratings are consistent with the finding that the ISA-I system was more effective in reducing speeds than ISA-A. The ISA-A system, however, was deemed more satisfying than ISA-I after exposure. One explanation why drivers found the ISA-A system more satisfying than the ISA-I system after exposure is that the auditory and visual warnings issued by the informative system may have been in greater conflict with the resources required by the driving task, rendering them more annoying or distracting than the tactile feedback from the ISA-A. Alternatively, drivers may have found this system less satisfying because it was more effective at restricting the speed at which they wanted to travel. Indeed, other research has found that ISA systems that are more effective at reducing speed (e.g., limiting ISA) are often deemed less acceptable by drivers (e.g., Päätalo et al., 2002; Várhelyi et al., 1998).

As with any preliminary work, this study has several limitations that should be noted. First, the study used a small sample, with only 15 participants in each group and this resulted in a lack of power, particularly for the individual speed zone analyses. Future research should use a larger number of participants from a range of ages and backgrounds in order to better understand how driver and road characteristics might moderate the effectiveness and acceptability of ISA.

Further, participants were only exposed to the ISA systems for a very short period of time—approximately half an hour. Research has demonstrated that, with long-term use, the effectiveness of ISA in reducing speed can decrease over time (see Regan et al., 2006; Várhelyi et al., 2004; Warner and Aberg, 2008), and that drivers can become over-reliant on the system (e.g., Hjämlöldahl and Várhelyi, 2004). As noted earlier, these effects, and particularly the issue of over-reliance, may be more pronounced in inexperienced drivers. Such maladaptive behavior is difficult to discover using short-term simulator studies. Similarly, the safety benefits that ISA may offer to inexperienced drivers might only emerge after longer exposure periods. It is only by conducting long-term studies that the full benefits and negative effects of ISA for inexperienced drivers can be realized.

Finally, although every attempt was made to make the simulated driving environments as realistic as possible, drivers were not exposed to a high number of other road users or to the time pressures that are part of everyday driving. These aspects of the simulated environment may have attenuated some of the potentially negative effects of ISA, particularly for the inexperienced drivers who are more vulnerable to the negative effects of high workloads (Cantin et al., 2009). It may also be the case that the effectiveness of the auditory feedback provided by the ISA-I system could be attenuated in real-world environments where noise from the driving environment (e.g., road noise, music, passenger conversations) might interfere with warning detection. These issues again highlight the need to examine the effects of ISA on inexperienced drivers’ driving performance in an on-road trial so that drivers have the opportunity to use the system under real driving conditions, while interacting with other road users.

This study is an important preliminary step in identifying the possible safety benefits and drawbacks of different ISA variants for young inexperienced drivers. The initial results are positive, with ISA reducing speeds for both driver groups in a range of driving locations and little evidence of negative adaptation. Further research should focus on examining the benefits and drawbacks of ISA for young inexperienced drivers over extended periods of time in an on-road environment.

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