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# The Effectiveness of an Intelligent Speed Assistance System with Real-Time Speeding Interventions for Truck Drivers: A Belgian Simulator Study

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**Abstract:** Speeding is one of the leading risk factors in road safety. Not only is it one of the leading causes of accidents, but it also has an extensive effect on the impact and consequences of accidents. This is especially the case for trucks, where the enforced speed limit is often dependent on local legislation and context rather than speed limit traffic signs. This study is part of the greater i-DREAMS project and aims to explore the effectiveness of an intelligent speed assistance system for truck drivers on different road types. To achieve this, a simulator experiment was performed with 34 professional truck drivers in Belgium. Participants first made a baseline drive, followed by two more drives, where they received visual information about the enforced speed limit but also visual and auditory warnings when exceeding the speed limit. The drives included different road environments with different speed limits. The results reveal a significant reduction in relevant parameters (i.e., average speed, minimum speed, maximum speed, and percentage of distance above the speed limit) when drivers received information and warnings about speeding while driving on a rural 1 × 1 road with a speed limit of 70 km/h (60 km/h for trucks). Further research is needed to validate this effect on other road types and under more-challenging conditions.

**Keywords:** truck simulator; speeding; intelligent speed assistance; interventions; driving behavior

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## 1. Introduction

It is estimated that 10–15% of all crashes and 30% of all fatal accidents are a direct result of speeding or inappropriate speed [1]. Increased speed increases not only the chance of an accident but also the severity of the crash. Because of trucks' large size and heavy weight, this is especially true for them. Therefore, when searching for effective ways to improve traffic safety, trucks are a good choice to focus on. In general, trucks annually travel a greater distance than any other type of road vehicle. This assumption is backed by traffic safety numbers. Records from 2015 show that trucks were responsible for 8.3% of the distance traveled by vehicles registered in Belgium, while only 2% of the total number of registered vehicles were trucks [2]. This suggests that with the same resources (i.e., number of target vehicles), a greater impact can be achieved by focusing on trucks. Traffic accident numbers for 2019 also show that a truck was involved in 5.2% of injury accidents, while only 1.9% of all registered vehicles were trucks [3]. Accidents involving trucks are were also deadlier: a truck was involved in 17% of all traffic fatalities in Belgium during 2019, and in most cases (15.3% of fatalities), as the opposing vehicle [4,5]. Similar numbers have been reported by the European Union (EU), where in 2018, 14.5% of all fatalities resulted from accidents involving heavy transport vehicles [6].

### 1.1. Intelligent Speed Assistance (ISA)

Intelligent speed assistance (ISA) is a type of advanced driver assistance system (ADAS) that aims to reduce speeding behavior by providing drivers with feedback about the enforced speed limit. Additionally, some ISA systems also can intervene by cutting engine power or by providing real-time feedback in the form of real-time interventions. From 2022 onward, the European Commission had mandated ISA for all new vehicles (including trucks) [7]. Different technologies are used to determine speed limits within ISA systems [8]. Camera-based technology can be used to recognize traffic signs, or speed maps can be used in combination with geolocation to determine speed limits. Some systems also use data-fusion techniques to use a combination of camera-based recognition and speed maps, such as to override speed map data in the case of roadworks [9]. The European legislation also states that the correct speed limit must be determined with 90% accuracy, although special conditions that extend beyond knowing the country of operation and current road type are exempt from this rule [10]. Apart from ISA systems installed by the original equipment manufacturer, aftermarket ISA solutions exist as dedicated units that can be installed in older vehicles.

### 1.2. Real-Time Interventions

Real-time interventions are part of an ADAS system and warn the driver on the threat of a specific event by using visual, auditory, and/or haptic feedback. Alternatively, the intervention system can also be used to inform the driver of the current driving parameters and persuade and nudge them toward safer driving [11,12]. To guarantee the optimal acceptance and effectiveness of the system, interventions should be designed with great care. A poorly designed intervention system might yield the opposite result of what it intends to achieve by annoying, confusing, and/or distracting the driver with the intervention itself [13,14].

Various studies and guidelines have suggested that a carefully designed multimodal, multistage warning system provides good results. Nonintrusive visual warnings can be used during a low-risk stage to nudge, persuade, or inform the driver, while more-urgent warnings should be multimodal and more intrusive [15–18]. The semantics of the warning message should also be easy to understand and preferably also trigger the desired reaction from the driver as a reflex (i.e., displaying a stop sign when necessary to stop); this is especially true for warnings that have higher urgency [19,20].

### 1.3. i-DREAMS Technology

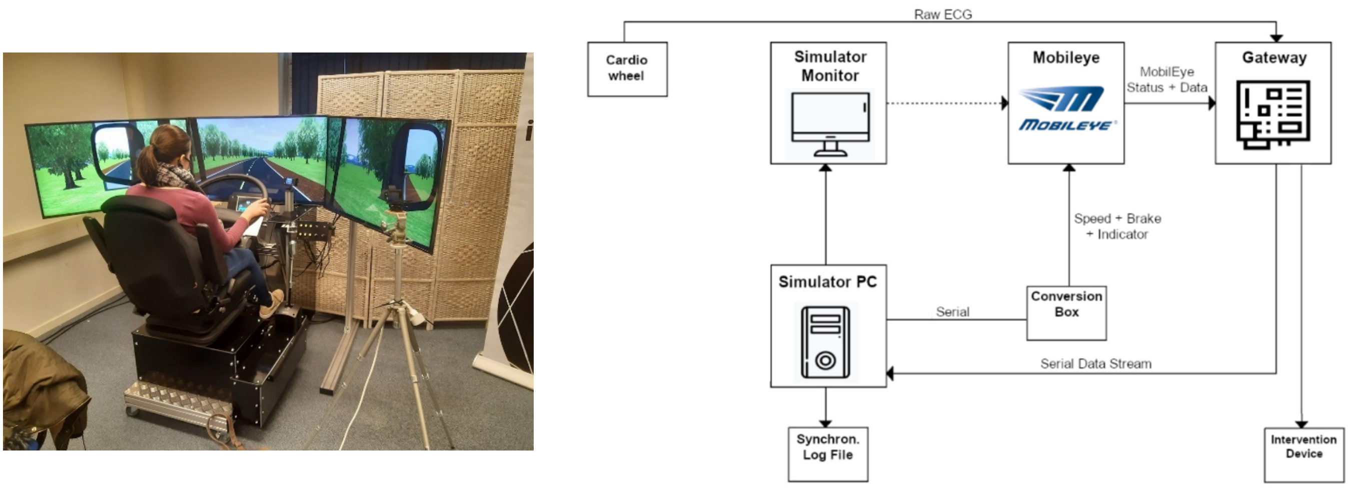
A Horizon 2020 project, i-DREAMS is funded by the European Union. The project aims to set up a platform that provides interventions and automated coaching to keep the driver within boundaries of safe operation, conceptualized by the project as the safe tolerance zone (STZ). These interventions are provided to the driver both post-trip and in real time. The post-trip interventions aim to motivate sustained behavioral change in the long term, while real-time interventions have the purpose of nudging a driver toward safer decision-making or demand immediate action from the driver when the STZ is being exceeded and thus dangerous driving or an avoidable accident is detected. The i-DREAMS real-time intervention technology includes an ISA system that provides drivers with real-time information about speed limits but also provides warnings when exceeding speed limits. To determine the thresholds, several modifying conditions are considered, including distraction, sleepiness, weather, and time of day. The i-DREAMS technology was developed for different vehicle types (car, truck, bus, tram, train) and will be deployed and validated in multiple European countries (Belgium, Germany, Greece, Portugal, the United Kingdom)

Driving simulators are commonly used in the automotive industry to develop human–machine interfaces (HMIs) [21]. They provide a risk-free environment in which driver behavior can be monitored under highly relevant, controlled, and repeatable conditions. To validate the i-DREAMS technology before usage during field trials, simulator experiments are performed to validate the technology. This paper describes an i-DREAMS simulator experiment in Belgium and aims to assess the effectiveness of the ISA system, for different road types on speeding behavior for professional truck drivers. To the best of our knowledge, the effectiveness of an ISA system for trucks as the one studied here, while accounting for differences in road type, has not yet been done before.

## 2. Materials and Methods

### *2.1. Data Collection Instruments*

This study used the DriveSimSolutions TruckSim driving simulator (see Figure 1a). The simulator replicates the seating position of a truck and uses authentic truck parts such as the steering wheel and turn indicator. A force feedback steering motor provided a realistic steering feel, while a digital instrument cluster provided the driver with information about vehicle speed, turn indicator status, and engine revolutions per minute. An automatic gearbox was configured in combination with two pedals (i.e., throttle and brake). Driving scenarios were programmed with STISIM Drive3 software, the simulated vehicle featured realistic vehicle dynamics for a truck. Visuals were rendered on three 43-inch monitors for a 135° field of view with a resolution of 5760 × 1080 pixels. The simulation software did run at a target frame rate of 30 frames per second (fps), but the frame rate was inconsistent and varied between 25 fps and 40 fps. The built-in speaker of the center monitor provided auditory feedback to replicate the sound of a truck engine from inside the cabin.




(**a**) (**b**)

**Figure 1.** Truck simulator setup used for the experiment: (**a**) DriveSimSolutions TruckSim simulator; (**b**) hardware architecture and data flow of the simulator setup.

An overview of the system architecture is provided in Figure 1b. Data were collected from a set of different sources and sensors. On the simulator computer itself, custom software was created to synchronize the data from all the different sources to a single datafile. Data were written to this file at every simulation step, with a frequency of approximately 30 Hertz. The driving simulator software provided variables on driver input and from the simulated environment. A Mobileye camera was faced at a split image from the central monitor of the simulator and received real-time information on vehicle speed, brake switch status, and turn indicator status from the driving simulator. The Mobileye system was used as a sensor for traffic sign recognition, lane departure, and vehicle-following parameters. These parameters were made available on a Mobileye controller area network (CAN) bus and read by the Cardiogateway. A serial universal asynchronous receiver–transmitter communication protocol was created to transmit variables provided by the Cardiowheel and the Mobileye camera from the Cardiogateway to the simulator computer, where they were synchronized with simulation variables and written to the datafile. A detailed overview of the i-DREAMS hardware is available in i-DREAMS deliverable 4.4 [22]. The simulator architecture is extensively elaborated in i-DREAMS deliverable 5.2 [21].

### *2.2. Human–Machine Interface (HMI)*

A prototype version of the i-DREAMS intervention device, which can be seen in Figure 2, was used to provide visual warnings and information. The intervention device is a small touch-sensitive HMI unit that can be placed inside the vehicle within the driver's view. For this experiment, it was placed on the right-hand side of the steering wheel, a little higher than the instrument cluster, simulating the position where it would be placed on the dashboard or the windshield in a vehicle (see Figure 1a). The intervention device is based on a 2.4-inch Nextion HMI and features a color display with a resolution of 320 × 240 pixels [23]. Auditory interventions were provided in high-risk situations through the speaker of the center monitor of the driving simulator.


**Figure 2.** The i-DREAMS intervention device [23].

This experiment used the i-DREAMS real-time intervention strategy, which was based on recommendations from i-DREAMS deliverable 3.3 [24], presented in i-DREAMS deliverable 3.6 [25]. It features a set of intervention strategies with variable thresholds, where the thresholds were determined by the i-DREAMS STZ and were based on a combination of modifying conditions (i.e., weather, sleepiness, distraction). For this experiment, only the headway and speeding interventions were enabled, where sleepiness was used as a condition to modify the speeding thresholds. However, for this paper, only speeding behavior was analyzed. The ISA system includes speeding warnings as multilevel interventions. The value of the current speed limit was based on traffic sign recognition, but it was adapted for trucks. Hence, for this experiment, the speed limit for trucks in a Belgian (Flemish) context was displayed on the intervention device, which differs from speed limits displayed on traffic signs (see Table 1). For instance, on the road section with a speed limit of 60 km/h for trucks, the speed limit for cars was 70 km/h, and traffic signs also showed a speed limit of 70 km/h.

**Table 1.** Overview of the difference in speed limit sign and enforced speed limit for trucks in a Belgian (Flemish) context.

| Road Section | Speed Sign | Speed Limit for Trucks (>3.5 T) |
|---|---|---|
| Rural road with 2 lanes (1 × 1) | 70 km/h | 60 km/h |
| Rural road with 4 lanes (2 × 2), divided by median section | 90 km/h | 90 km/h |
| Motorway with 4 lanes (2 × 2), divided by median section | Motorway sign | 90 km/h |

The principle of software-in-the-loop simulation was used. A prototype of the i-DREAMS real-time intervention software ran directly on the simulation computer. To take variables from the simulator environment as inputs to trigger interventions, user datagram protocol (UDP) communication was used to transmit simulation variables from the driving simulator software to the i-DREAMS software in real time.

### *2.3. Experiment Design*

The experiment used a design discussed in i-DREAMS deliverables 3.4 [26] and 5.2 [21]. It featured a within-subject design where each participant first performed a test drive (without real-time interventions) to grow accustomed to the simulator. To investigate the effects of the ISA system, each driver performed three 15 min drives, during which data were collected: one without ISA (drive 1, baseline); one with ISA and real-time interventions enabled but at a low sleepiness setting (drive 2, intervention); and one with ISA and real-time interventions enabled and at a very high sleepiness setting (drive 3, intervention + high sleepiness), see Table 2.

**Table 2.** Overview of real-time interventions and modifying conditions for each drive.

| Drive | Interventions | Modifying Condition |
|---|---|---|
| 1 | n/a | n/a |
| 2 | Speeding, tailgating, forward collision | n/a |
| 3 | Speeding, tailgating, forward collision | Sleepiness: very high |

Notes: n/a—not applicable, because interventions were disabled for drive 1. The thresholds during drive 2 were unmodified.

Prior to drive 2, where ISA and real-time interventions were enabled for the first time, participants were not given any information about the technology and were not told that their speeding behavior would be measured. They were just asked to drive as they normally would.

To prevent a situation where participants would already know that speeding was going to be monitored before performing the baseline, the order of drives (i.e., whether ISA and interventions were enabled) was kept the same for each participant. Throughout the duration of each drive, all modifying conditions (i.e., sleepiness, weather, distraction) were set to a constant value to avoid the unintentional modification of speeding thresholds. Importantly, drive 3 was performed shortly after drive 1 and drive 2; hence, although a very high value for sleepiness was manually set within the intervention algorithm for drive 3, it was very unlikely that drivers were really experiencing substantially higher levels of sleepiness. Except the instruction "imagine that you are feeling very sleepy", no additional measures to induce sleepiness were taken. This decision was made mainly out of ethical and practical considerations as it would be unethical but also impractical to ask professional truck drivers to participate in a simulation experiment in a sleepy condition. However, during each drive, drivers were asked to self-report their sleepiness on the Karolinska sleepiness scale (KSS) [27] as a score from 1 (extremely alert) to 10 (extremely sleepy). The main purpose of the experiment was to investigate the effect of ISA compared to no ISA. Additionally, if significant differences in sleepiness between the drives are monitored, the effect of modifying the thresholds on the basis of sleepiness can also be assessed. In case no significant differences in sleepiness can be monitored, at least the modified threshold might indicate how drivers respond to the same intervention, but with different thresholds.

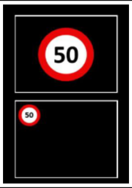
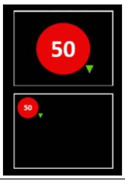
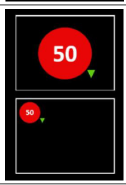
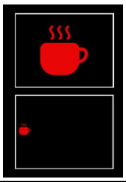
Because modifying conditions were kept constant for the duration of each drive, thresholds also remained constant throughout each simulated drive. See Table 3 for an overview of the resulting thresholds for speeding that were used during the experiment during drive 2 and drive 3. During drive 1, thresholds were not applicable, because interventions were disabled.

**Table 3.** Thresholds of the real-time intervention for speeding.

| Drive | Enforced Speed Limit | Speeding Threshold 1 | Speeding Threshold 2 |
|---|---|---|---|
| 2 | 60 km/h | 66 km/h | 69 km/h |
| 2 | 90 km/h | 99 km/h | 103.5 km/h |
| 3 | 60 km/h | 64.08 km/h | 66.12 km/h |
| 3 | 90 km/h | 96.12 km/h | 99.18 km/h |

A combination of visual and auditory warnings was provided as real-time interventions upon exceedance of speeding thresholds, with increasing intrusiveness and usage of multimodal warnings as the situation became more dangerous. An overview of the visual and auditory warnings is provided in Table 4.

**Table 4.** Overview of warnings for speeding and sleepiness used during the experiment [28].

| Intervention Stage | Visual Warning | Description Visual Warning | Auditory Warning |
|---|---|---|---|
| Normal driving—speed limit detected |   | Statically displayed as large icon for 1 s, then continuously displayed as a small icon | None |
| Dangerous driving—exceeding threshold 1 |   | Statically displayed as large icon for 1 s, then continuously displayed as a small icon | None |
| Avoidable accident—exceeding threshold 2 |   | Flashing as large icon for 1 s, then continuously displayed as a small icon | Auditory chime |
| Informative—sleepiness very high |  | Flashing display of red coffee cup icon for 1 s, then small static icon displayed. | Upon detection: yawn sound |

### 2.4. Driving Scenarios

The driving scenarios used during this experiment were modeled to represent a typical Belgian environment and are based on recommendations from i-DREAMS deliverable 5.2 [21]; see Figure 3 for screenshots. Three types of road sections were considered: a rural environment with a 1 × 1 road and speed limit signs of 70 km/h; a rural environment with a 2 × 2 road, separated by a dedicated middle section and speed limit signs of 90 km/h; and a motorway environment, with a 2 × 2 road, started by a blue motorway sign and separated by a dedicated middle section. In each of these sections, there are several 700 m segments without leading vehicles that were used for the evaluation of speeding behavior. Before and after these sections, there were additional buffer sections with similar conditions that allowed the drivers to speed up and slow down outside of the analyzed section when transitioning to a section with different conditions. To decrease the possibility of order effects [29], the order of the road sections was randomized across three scenarios. The order of the scenarios (i.e., A, B, C/B, C, A) was alternated between participants. The total length for each scenario was approximately 15 km and took about 15–25 min to complete. Weather conditions were neutral daylight, overcast without excessive sun or shadows, and the view was never obstructed by rain, fog, or sun.


(**a**) (**b**) (**c**)

**Figure 3.** Screenshots of the different road types used during the experiment: (**a**) rural road with 1 × 1 lanes and a speed sign of 70 km/h; (**b**) rural road with 2 × 2 lanes and a speed sign of 90 km/h; (**c**) motorway with 2 × 2 lanes and a motorway sign.

### 2.5. Participants

Data were collected for 36 participants. Owing to simulator sickness, two participants were excluded from the results. This led to a sample size of 34 participants, which consisted of 6 women and 28 men. Various platforms were used to recruit drivers; all participants were currently active professional truck drivers, except for two truck driver coaches. The sample featured a wide distribution of age, from 22 to 61 years, with an average of 41.97 years. The distribution of participants according to gender, weekly mileage, and transport type is shown in Figure 4. With regard to distance driven per week, 4 drivers drove less than 500 km/week, 7 drove 500–1000 km/week, 9 drove 1000–2000 km/week, 12 drove more than 2000 km/week, and for 2 participants, this was not applicable (driver coaches). With regard to transport type, 5 were active in construction; 5 performed distribution; 2 were active in heavy haul; 9 were active in long haul, with trips usually shorter than 300 km; 11 were active in long haul, with trips usually longer than 300 km; and for 2 participants, this was not applicable (driver coaches).

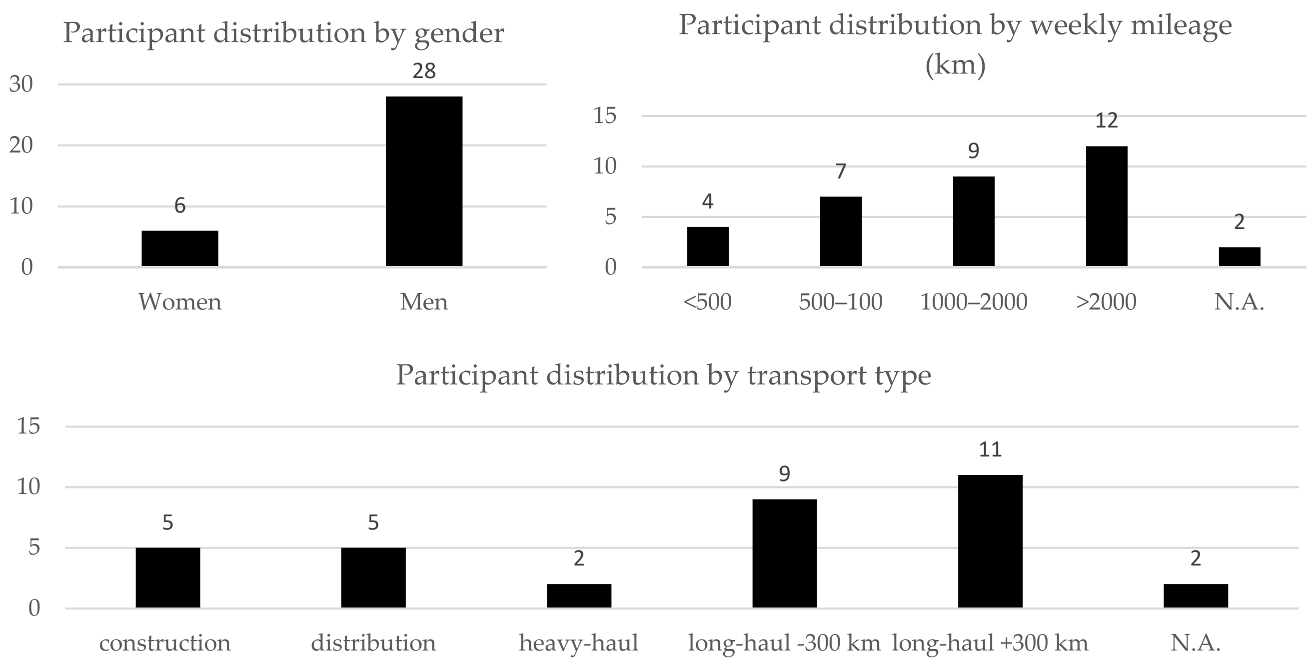



**Figure 4.** Graphical overview of participant distribution by gender, weekly mileage, and transport type.

## 3. Results

### *3.1. Speeding Behavior*

A repeated-measures analysis of variance was used to analyze speeding behavior throughout the selected sections of interest. Mauchly's test of sphericity was used to check whether the null hypothesis of assumed sphericity was violated. If violated, the degrees of freedom (dfs) were adjusted to compensate for the inflation of the F-value. For a Greenhouse–Geisser $\varepsilon <= 0.75$, the Greenhouse–Geisser correction was used. For a Greenhouse–Geisser $\varepsilon > 0.75$, the Huyn–Feldt correction was used.

The statistical significance of the within-subject effect of the drive (i.e., drive 1—no interventions; drive 2—interventions; drive 3—interventions with modified thresholds owing to sleepiness) for various speed parameters across different road sections is reported in Table 5. With significant at the 5% level, the null hypothesis that real-time interventions do not influence driving parameters was rejected. The results reveal there were significant effects between drives on both sections with a speed limit of 60 km/h. This was the case for average speed, minimum speed, maximum speed, and percentage of distance (5%) above the speed limit. For the road sections with a speed limit of 90 km/h, there was a significant effect on the minimum speed only on the motorway section.

**Table 5.** Within-subject effects for driving parameters related to speeding across different road sections.

| Road Section | Parameter | dfs | F | *p* |
|---|---|---|---|---|
| Rural—60 km/h—1 | Average speed | 2, 64 | 13.682 | **<0.001** |
| | Minimum speed | 1.777, 56.867 | 15.716 | **<0.001** |
| | Maximum speed | 2, 64 | 5.081 | **0.009** |
| | Percentage of distance (5%) above limit | 2, 64 | 13.405 | **<0.001** |
| | Percentage of distance below limit | 1.416, 45.326 | 1 | 0.351 |
| Rural—60 km/h—2 | Average speed | 2, 64 | 6.674 | **0.002** |
| | Minimum speed | 2, 64 | 5.282 | **0.008** |
| | Maximum speed | 2, 64 | 5.664 | **0.005** |
| | Percentage of distance (5%) above limit | 1.522, 48.715 | 14.487 | **<0.001** |
| | Percentage of distance below limit | 1.381, 44.187 | 0.298 | 0.661 |
| Rural—90 km/h | Average speed | 2, 64 | 0.496 | 0.611 |
| | Minimum speed | 2, 64 | 0.940 | 0.396 |
| | Maximum speed | 2, 64 | 0.352 | 0.705 |
| | Percentage of distance (5%) above limit | 1.119, 64 | 0.027 | 0.893 |
| | Percentage of distance below limit | 2, 64 | 1.307 | 0.278 |
| Motorway—90 km/h | Average speed | 2, 64 | 2.325 | 0.106 |
| | Minimum speed | 2, 64 | 5.969 | **0.004** |
| | Maximum speed | 1.742, 55.736 | 0.614 | 0.523 |
| | Percentage of distance (5%) above limit | 2, 64 | 0.554 | 0.577 |
| | Percentage of distance below limit | 1.665, 53.279 | 2.120 | 0.138 |
| Across all sections | Average speed | 2, 64 | 6.058 | **0.004** |
| | Percentage of distance (5%) above limit | 1.645, 52.630 | 19.085 | **<0.001** |
| | Percentage of distance below limit | 2, 64 | 1.278 | 0.286 |

Table 6 shows descriptive statistics for driving parameters across all sections. For driving parameters where drive had a significant effect, a post hoc pairwise comparison with the Bonferroni correction was performed, and significant effects between drives are indicated as subscript in Table 6. Post hoc tests for the first section with a speed limit of 60 km/h revealed a significant reduction in average speed between drive 1 and drive 2 ($p < 0.001$) and between drive 1 and drive 3 ($p = 0.005$); a reduction in the minimum speed between drive 1 and drive 2 ($p < 0.001$) and between drive 1 and drive 3 ($p = 0.001$); a reduction in the maximum speed between drive 1 and drive 2 ($p = 0.005$); and a reduction in the percentage of distance (5%) above the speed limit between drive 1 and drive 2 ($p < 0.001$) and between drive 1 and drive 3 ($p = 0.001$). Similar effects were found for the second rural section, with a speed limit of 60 km/h: a reduction in the average speed between drive 1 and drive 2 ($p$ = 0.022) and between drive 1 and drive 3 ($p$ = 0.012); a reduction in the minimum speed between drive 1 and drive 2 ($p$ = 0.035) and between drive 1 and drive 3 ($p$ = 0.050); a reduction in the maximum speed between drive 1 and drive 2 ($p$ = 0.023) and between drive 1 and drive 3 ($p$ = 0.022); and a reduction in the percentage of distance (5%) above the speed limit between drive 1 and drive 2 ($p < 0.001$) and between drive 1 and drive 3 ($p$ = 0.003). The significant effect of driving on the minimum speed on the motorway sections translated into a significant increase in the minimum speed between drive 1 and drive 3 ($p$ = 0.048) and between drive 2 and drive 3 ($p$ = 0.003). Driving parameters were also averaged per drive across all road sections to compare the effects of intervention throughout an entire drive. The minimum and maximum speeds were not considered. This revealed a significant reduction in the average speed between drive 1 and drive 2 ($p$ = 0.013) and a significant reduction in the distance spent (5%) above the speed limit between drive 1 and drive 2 ($p < 0.001$) and between drive 2 and drive 3 ($p < 0.001$).

**Table 6.** Descriptive statistics of driving parameters.

| Road Section | Drive | Average Speed (km/h) | | Minimum Speed (km/h) | | Maximum Speed (km/h) | | Percentage of Distance (5%) above Speed Limit (%) | | Percentage of Distance below Speed Limit | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Rural—60 km/h—1 | 1. Baseline | **65.09**$_{1,2}$ | 0.83 | **61.38**$_{1,2}$ | 0.97 | **68.15**$_{1}$ | 0.94 | **63.04**$_{1,2}$ | 6.91 | 1.37 | 0.79 |
| | 2. Intervention | **61.16**$_{1}$ | 0.58 | **57.06**$_{1}$ | 0.72 | **65.09**$_{1}$ | 0.65 | **30.89**$_{1}$ | 5.54 | 3.34 | 1.94 |
| | 3. Intervention + sleepiness | **62.14**$_{2}$ | 0.72 | **57.92**$_{2}$ | 0.58 | 65.80 | 0.94 | **36.56**$_{2}$ | 6.07 | 1.23 | 0.71 |
| Rural—60 km/h—2 | 1. Baseline | **64.08**$_{1,2}$ | 1.08 | **60.77**$_{1,2}$ | 1.12 | **67.21**$_{1,2}$ | 1.04 | **52.37**$_{1,2}$ | 7.69 | 5.19 | 3.50 |
| | 2. Intervention | **61.52**$_{1}$ | 0.94 | **58.25**$_{1}$ | 0.86 | **64.48**$_{1}$ | 1.04 | **22.24**$_{1}$ | 5.96 | 2.75 | 1.41 |
| | 3. Intervention + sleepiness | **61.02**$_{2}$ | 0.72 | **58.21**$_{2}$ | 0.83 | **63.9**$_{2}$ | 0.72 | **25.73**$_{2}$ | 6.23 | 4.61 | 2.09 |
| Rural—90 km/h | 1. Baseline | 82.84 | 1.62 | 78.77 | 1.62 | 87.19 | 1.84 | 3.82 | 1.51 | 28.78 | 7.53 |
| | 2. Intervention | 81.11 | 1.51 | 76.00 | 1.51 | 86.29 | 1.69 | 3.21 | 2.27 | 43.93 | 7.07 |
| | 3. Intervention + sleepiness | 81.47 | 1.51 | 77.90 | 1.58 | 85.57 | 1.58 | 3.66 | 3.07 | 38.08 | 7.46 |
| Motorway—90 km/h | 1. Baseline | 87.62 | 0.61 | **81.32**$_{2}$ | 1.08 | 91.40 | 0.68 | 8.10 | 3.80 | 6.91 | 2.29 |
| | 2. Intervention | 86.83 | 0.9 | **80.06**$_{3}$ | 1.30 | 90.94 | 1.04 | 7.07 | 2.47 | 10.26 | 3.48 |
| | 3. Intervention + sleepiness | 88.70 | 0.50 | **84.71**$_{2,3}$ | 0.83 | 92.05 | 0.58 | 4.18 | 2.12 | 3.34 | 1.49 |
| All sections combined | 1. Baseline | **74.92**$_{1}$ | 0.76 | | | | | **31.82**$_{1,2}$ | 3.61 | 10.56 | 2.78 |
| | 2. Intervention | **72.65**$_{1}$ | 0.72 | | | | | **15.85**$_{1}$ | 2.88 | 15.01 | 2.24 |
| | 3. Intervention + sleepiness | 73.33 | 0.54 | | | | | **17.53**$_{2}$ | 2.99 | 11.83 | 2.11 |

Note: means that share a subscript are significant at the 5% confidence level after the Bonferroni correction. Standard deviation abbreviated to SD.

### *3.2. Speed Distribution*

Figure 5 shows the distribution of the average speed among drivers for one of the two sections with a speed limit of 60 km/h. For the baseline drive, it is clear that in general, the average speed is above the speed limit of 60 km/h. There is a roughly even distribution ranging from 56 km/h to 70 km/h, with only few drivers having average speeds above 70 km/h. For drive 2 and drive 1, where the ISA system was active, the average speed is much more concentrated around the speed limit, 60 km/h. The shift in distribution might indicate that some of the drivers who were previously driving 65 km/h or above were more inclined to drive at a lower speed, closer to the speed limit, when the ISA system was enabled.

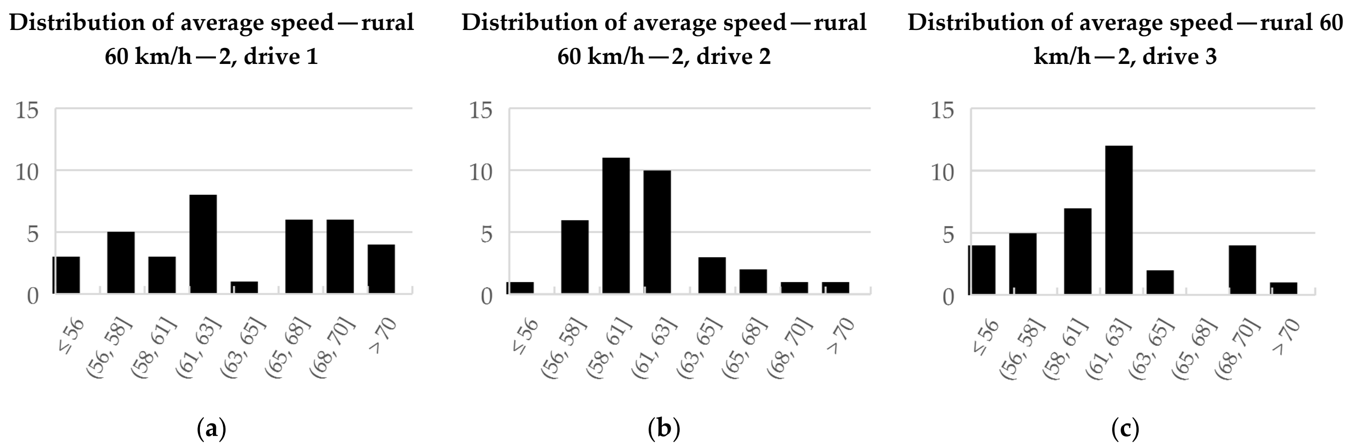



**Figure 5.** Distribution of average speed for the rural road section with a speed limit of 60 km/h (Section 2): (**a**) baseline drive; (**b**) intervention drive; (**c**) intervention + sleepiness drive.

Figure 6 shows the distribution of the average speed among drivers for the rural road section with a speed limit of 90 km/h. For the baseline drive, there is a clear concentration around the speed limit of 90 km/h, indicating that most drivers were aiming to drive at the speed limit, but not much above that. Compared with the rural road type with a speed limit of 60 km/h, it seems drivers less intended to drive above the speed limit. When comparing the first drive (baseline) with drive 2 and drive 3 (with the ISA system enabled), it is clear that for both drives where the ISA system was active, the distribution is much less concentrated around the speed limit. Although, according to the RMANOVA, this finding was not significant enough to reduce the average speed, it seems that ISA has an influence on the speeding behavior for several drivers, with more drivers having lower average speeds.

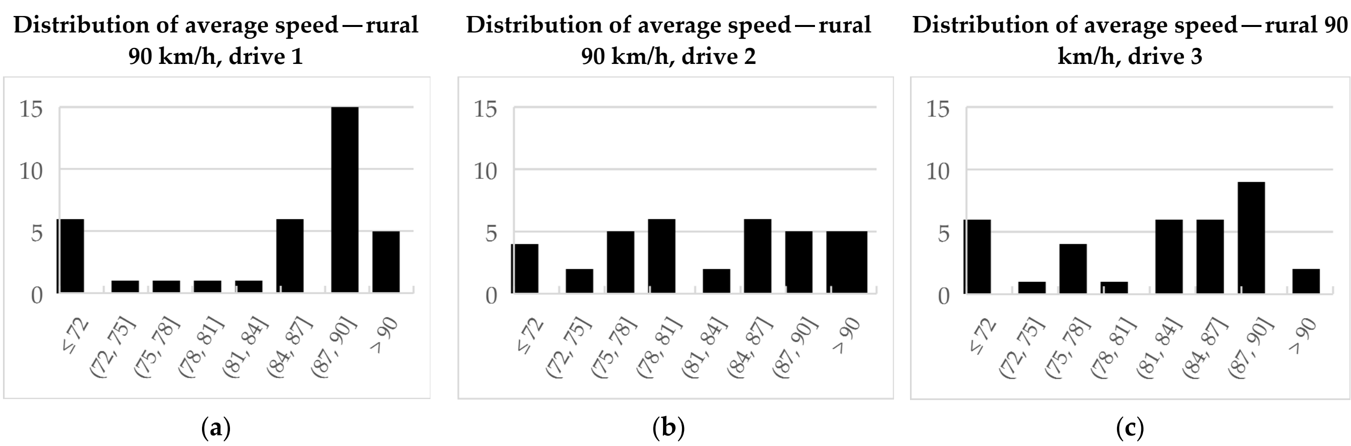



**Figure 6.** Distribution of average speed for the rural road section with a speed limit of 90 km/h: (**a**) baseline drive; (**b**) intervention drive; (**c**) intervention + sleepiness drive.

### *3.3. Self-Reported Sleepiness*

Throughout the experiment, drivers were asked to self-report their sleepiness on the KSS as a score from 1 (extremely alert) to 10 (extremely sleep) during each of the three drives. Table 7 shows the mean and standard deviation of KSS scores reported by drivers. Descriptive statistics show an increase in self-reported sleepiness from drive 1 to drive 2 and from drive 2 to drive 3. The difference is not significant between drive 1 and drive 2 ($p = 0.38$) or between drive 2 and drive 3 ($p = 0.21$). A significant increase in self-reported sleepiness does, however, exist between drive 1 and drive 3 ($p = 0.04$), indicating that drivers did feel sleepier on the final drive compared to the first drive.

**Table 7.** Descriptive statistics of self-reported sleepiness by drivers throughout the experiment.

| Drive | Average KSS Score (1–10) | |
|---|---|---|
| | Mean | SD |
| 1. Baseline | 2.55 | 0.88 |
| 2. Intervention | 2.75 | 0.97 |
| 3. Intervention + sleepiness | 3.08 | 1.19 |

Still, the mean KSS score for drive 3 is still very low, indicating very low sleepiness (KSS score 3 = alert). Only one driver reported a score of 6 (some signs of sleepiness), whereas all the other drivers reported scores of 5 (neither alert nor sleepy) or lower. Therefore, it can be concluded that not enough sleepiness was present during the experiment, drive 3 in specific, to draw conclusions on the effectiveness of the interventions on sleepy drivers.

## 4. Discussion

The purpose of this experiment was to analyze the effect of an ISA system on speeding behavior for different road types. A significant reduction was found for almost all relevant driving parameters between a drive without ISA or speeding interventions and between a drive with ISA and speeding interventions, but only for road sections with a speed limit of 60 km/h and not on road sections with a speed limit of 90 km/h. Before any conclusions on this effect can be drawn, it is useful to consider common reasons for speeding. Previous research has indicated that drivers might engage in a riskier driving style when they are stressed [30], which is often caused by organizational factors such as just-in-time delivery and long working hours [31]. During the experiment, no initiatives to create time pressure for the drivers were created; instead drivers were asked to drive as they would normally drive. Therefore, it seems unlikely that drivers were exceeding the speed limit because of time pressure during the experiment, so on the basis of the current experiment, no conclusions can be drawn on the effectiveness of the ISA system to reduce speeding caused by time pressure.

Sleep quality and sleep deprivation may also be related to the speeding behavior of truck drivers [32]. This behavior might be attributed to drivers' becoming more impatient or being less aware of the surrounding environment. To cope with the additional risks caused by sleepiness, the ISA system was made "smart" in way that thresholds are modified when sleepiness is detected among drivers. To validate the acceptance of these stricter thresholds, a third drive was included to simulate the condition (in terms of thresholds only) where drivers were sleepy. Because of ethical and practical limitations during this pilot test of the presented ISA system, actual sleepiness could not be induced among drivers. Instead, drivers were asked to self-report sleepiness during each drive. The levels of sleepiness that were monitored were very low for almost all drivers. Therefore, according to the collected results, it is not possible to draw conclusions on how the presented ISA system, with modified thresholds for sleepiness, influences speeding behavior among sleepy drivers. The results do, however, indicate that acceptance of the presented ISA system was still high, even with the stricter thresholds that were set during the third drive.

Speeding might also occur because drivers are unaware either of their current speed or of the current speed limit. This type of speeding is mostly unintentional and limited in terms of speed limit exceedance [33]. Additionally, speeding might be normative, where it is the norm among drivers, influenced by peers or surrounding traffic to drive above the speed limit [34].

Given the abovementioned reasons for speeding, this study tried to explain the speeding behavior and effect of the ISA system that was monitored during the experiment. First, an ISA system may be most effective in situations where the driver is unaware of the speed limit because the speed limit signs contradict the enforced speed limit. On the road sections with a speed limit of 60 km/h, traffic signs with a speed limit of 70 km/h were placed along the road. For road sections with a speed limit of 90 km/h, there were no contradicting traffic signs. This is a realistic situation for trucks in Belgium on these types of roads. The ISA system used and displayed the enforced speed limits; for instance, the ISA system enforced the speed limit of 60 km/h for trucks where a speed sign of 70 km/h was shown.

It is possible that participants were not aware of the enforced speed limit of 60 km/h without ISA. This is relevant as many truck drivers are operating in international transport and might not be fully aware of the many rules for enforced speed limits for trucks in Europe. Therefore, these results may suggest that ISA can be a useful tool for truck drivers, by apprising them of local speed limits. Of course, this is under the condition that the used ISA system has the capabilities of displaying speed limits for trucks, which requires at least some sort of speed mapping because it cannot be performed by camera-based traffic sign recognition alone. This raises the question of what the effect would be of an ISA system that does not display the correct speed limits for trucks, as it could increase driving speeds. More research is needed to investigate the effect of inaccurate ISA systems on speeding behavior.

The mean values for maximum and average speeds suggest that most participants were aware of the 60 km/h speed limit given that they mainly stayed below 70 km/h during the baseline drive for road sections with a speed limit of 60 km/h. Additionally, driving parameters for road sections with a speed limit of 90 km/h indicate that even during the baseline drive, participants were above the speed limit only for a limited percentage of distance, and in general, speeds were already below the speed limit, leaving very little room for improvement when using an ISA system. This leads to another possible explanation: truck drivers might be more inclined to speed on road sections with lower speed limits because it is the norm among drivers. An ISA system is an effective way of reducing speed on these road sections. This also makes sense given that trucks rarely exceed 90 km/h as they are normally equipped with a speed limiter that limits engine power when speed exceeds 80 km/h or 90 km/h (depending on the country: 90 km/h in Belgium), although no speed limiter was active during this simulation experiment.

The results also suggest that the modification of thresholds for speed warnings that were used in this experiment has very little effect on speeding behavior. A statistical analysis found no relevant significant effects on driving parameters between drive 2 (less strict threshold setting) and drive 3 (stricter threshold setting). Within i-DREAMS, the threshold modification that was used for this experiment would be aimed at drivers with high levels of sleepiness. However, participants were asked to self-report their level of sleepiness during the experiment, and none of the participants reported any score high enough to trigger the modification of thresholds, meaning that according to the collected dataset, it is impossible to draw conclusions on the effectiveness of modifying thresholds for sleepy drivers. Trends in driving parameter means seem to indicate increased speed for drive 3, where thresholds were stricter. This might be explained by the fact that drive 3 was always performed as the final drive, so participants could have been more confident in the driving simulator environment or might have been less motivated to showcase "good" driving behavior after several sessions.

*Limitations and Future Work*

This experiment was certainly subject to limitations. First, drivers were not actually in a sleepy condition when testing the thresholds for sleepiness during the third drive. Additionally, 15 min drives without time pressure might not be representative of the actual driving conditions experienced by truck drivers. Notwithstanding, as a pilot test for the presented ISA system, this experiment proved it could help to reduce speeding in certain conditions. Future work should focus on exposing truck drivers to more-challenging conditions, including induced sleepiness, adverse weather, longer trip durations, and increased time pressure. Additionally, future work could focus on determining whether the differences in speeding behavior between road types with a speed limit of 60 km/h and road types with a speed limit of 90 km/h can be attributed to the road type itself or to the fact that for trucks the actual speed limit is different from that posted on the speed signs on the road. As a next step, it would also be useful to examine how drivers interact with the ISA system and how the ISA system might influence speeding in a more naturalistic driving environment over longer time periods. This would reduce the possibility that drivers change their driving behavior because they are exposed to an unfamiliar environment (driving simulator) and know they are being monitored. Moreover, it would help to provide insight into how the ISA system influences speeding behavior in the long term.

## 5. Conclusions

Speeding is one of the leading causes of traffic accidents. ISA systems are designed to reduce speeding by providing drivers with warnings and feedback. From 2022 onward, these systems will become mandatory for new vehicles in the European Union. As part of the i-DREAMS project, this study aimed to investigate the effectiveness of an ISA system, specifically for trucks. A simulator experiment was held with 34 professional truck drivers in Belgium, where speeding behavior during a drive without ISA was compared with drives where ISA was enabled for different road types. The ISA system provided warnings when speeding was detected, and two sets of thresholds were tested. Each drive consisted of four road sections: two rural sections where the enforced speed limit for trucks (60 km/h) was different from the speed limit displayed on traffic signs (70 km/h), one rural section with a speed limit of 90 km/h, which was also indicated by speed limit signs; and one motorway section where the speed limit was 90 km/h for trucks. The driving parameters were collected from the driving simulator, and a statistical analysis was performed by using a repeated-measures analysis of variance. The results indicated that the ISA system that is part of the i-DREAMS set of technologies significantly reduced the average speed, maximum speed, minimum speed, and percentage of distance above the speed limit for both rural road sections with a speed limit of 60 km/h, suggesting that the ISA system is an effective method of reducing speeding behavior for this specific type of road. However, no significant effects were found for the road sections where the speed limit was 90 km/h. Using stricter thresholds also did not cause any significant effects. Although this study has some limitations, mostly in terms of the driving conditions and challenges commonly faced by truck drivers, it was still useful as a pilot test of the i-DREAMS ISA system for truck drivers.

It can be concluded that the tested ISA system, tailored for trucks, was effective on rural roads with a speed limit of 60 km/h where the speed limit is inferred from context rather than speed signs. To confirm these findings and to further assess the effectiveness of ISA systems for trucks, more research is needed to compare road types, with lower speed limits, that were not considered in this experiment. Additionally, more research is also required to validate the effectiveness of the ISA system under more-realistic and more-challenging driving conditions.

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