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Article

Driving Behaviour and Usability: Should In-Vehicle Speed Limit Warnings Be Paired with Overhead Gantry?

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Abstract: Variable speed limits (VSL) aim at improving safety and traffic fluidity by increasing drivers' awareness. In the present simulator study, VSL displayed on overhead gantries on a motorway were also displayed on a mobile phone, fixed on the vehicle's centre console, with distance-based triggers (250 m vs. 500 m from the overhead gantry). Results showed drivers (N = 20) complied with the in-vehicle information, which was congruent with the upcoming gantry. The sooner the in-vehicle VSL, the faster the speed when speed limits increased. Similarly, the sooner the in-vehicle VSL, the slower the speed when speed limits decreased. Later in-vehicle VSL resulted in lower speed homogeneity, which is a safety concern. Speed homogeneity was greater when no in-vehicle VSL were displayed. Finally, the 70 mph VSL were affecting driving behaviour differently. These results suggested that there might be traffic disruption and more erratic longitudinal vehicle control on real roads.

Keywords: driving behaviour; speed limit; in-vehicle information; human–machine interaction; mobile phone; road safety

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1. Introduction

Intelligent Speed Adaptation (ISA) technologies are systems enabling vehicles to detect speed limits and share that information with the driver. Among ISA systems, variable speed limits (VSL) are dynamic speed limits usually conveyed via digital devices such as overhead gantries. They are deployed on specific sections of motorways depending on the local traffic conditions. Ultimately, they are expected to increase comfort, journey time reliability, traffic fluidity (e.g., congestion during peak hours) and road safety by pre-warning drivers of speed changes related to upcoming events and traffic conditions (e.g., lane closure, roadworks area). In addition, in-vehicle VSL could prove useful to convey information to the drivers when road visibility is low (e.g., rain, fog, night-time).

Previous driving simulator experiments investigated driver's acceptance and usefulness towards VSL [1], induced mental workload, perception [2] and compliance [2–5], even making use of a traffic simulation model [6]. Results showed that some drivers were not able to comply with VSL given that they could fail to notice a speed limit change [4], but also that VSL signs showed the best compliance when each speed limit sign was displayed separately per lane on an overhead gantry [2,3]. Drivers exposed to VSL generally drove with less variation and at uniform speed [5]. These findings have recently been analysed in the scope of additional in-vehicle information which can be conveyed via mobile phones, allowing older vehicles to be connected. Driving simulator studies investigating the effect of in-vehicle information on driving behaviour showed speed warnings were efficient in reducing speed, directing driver's attention to the appropriate speed, and decreasing unintentional speed [7], even with lower speed limits [8]. Speed homogeneity is also positively affected by in-vehicle speed warnings [9].

Connected vehicle features work by receiving traffic information from communication infrastructure installed along a route or from other vehicles that are equipped with so called car-to-car communication capabilities. These features already exist and are usually embedded in satnav and GPS application (e.g., TomTom, Waze and Google Maps). One of the assets of additional in-vehicle information is to display warnings at different times and location to ensure drivers have a sufficient comprehension of their environment, especially when the visibility is poor due to weather conditions, heavy traffic or road works (see [10]). It may also help drivers notice VSL signs they failed to notice, even on a familiar road [4]. Additional in-vehicle has the potential to support situation awareness [11], which consists of three levels, namely perception (e.g., what happened?), comprehension (e.g., what does it mean?) and projection (e.g., what is going to happen?). A good situation awareness may allow drivers to better anticipate oncoming events, road modifications or hazards. As a result, traffic safety and fluidity may take advantage of in-vehicle information such as VSL. A caveat could be the lack of congruency between in-vehicle information and the gantry, and its impact on driving behaviour in terms of safety (e.g., misinterpretation, distraction) and usability.

Previous research did not extensively assess in-vehicle VSL in terms of usability and acceptance, and the present study aims to address this gap. Drivers may be receptive to such a feature if it is safe to use, and neither annoying nor distracting. Additionally, as connected vehicles already share drivers' data with other parties (e.g., local authorities, car manufacturers, other road users), it seems important to assess to what extent users accept their on-road data to be used.

The purpose of the present driving simulator study was to evaluate the effects of a mobile phone app that informed drivers of upcoming speed limits already conveyed via an overhead gantry on driving behaviour, specifically longitudinal control. The in-vehicle information triggers were distance-based and varied across conditions, as previous research did not investigate this. The main hypothesis was that the combination of a mobile app and overhead gantries would have a different impact on drivers' speed control compared with the presence of overhead gantries only.

2. Method

2.1. Experimental Design

A mixed within and between subjects design with the within subjects factor *HMI* (Human–Machine Interface: with vs. without) and the between subjects factor *HMI trigger* (*trig250 m* vs. *trig500 m*) and was used (Table 1). Ten participants experienced the *trig250 m* condition, and another ten the *trig500 m* condition. In these experimental conditions, the speed limit was displayed on the telephone either 250 m (*trig250 m*) or 500 m (*trig500 m*) before the overhead gantry. In the baseline condition *noHMI*, no additional in-vehicle information was displayed on the telephone. This mixed experimental design allowed to compare speeds with and without the HMI, between the HMI triggers and verify that speeds without HMI were not already significantly different between groups. It also prevented potential carryover effects of learning from one experimental condition to the other. No demographics pre-checks were made but participants were distributed into the two experimental conditions to balance for age and gender as much as possible.

Table 1. Mixed within and between subjects experimental design. The number of participants per condition is shown in parentheses.

	Within Subjects Factor	
	No HMI	
	HMI	
Between subjects factor	*trig250 m (10)*	*trig500 m (10)*

2.2. Procedure

Participants were welcomed and filled out a consent form. Subsequently, they received a general introduction to connected vehicles while sitting into the driving buck. Specific information about the driving simulator were given, such as the automatic transmission, the force feedback steering unit and the bass shakers. Participants were told that the aim of the study was to gain more insight into an in-vehicle app conveying information on speed limits. This introduction was followed with a 5 min practice drive to get familiarised with the controllers.

The following main drive consisted of a 5 min drive approximately on a 5 miles long four-lane motorway track, without any HMI. The speed ranged from 50 mph to 70 mph. Participants were asked to start the engine on the rightmost lane, accelerate and follow the speed limits displayed on the overhead gantry according to the Highway Code, road safety and vehicle rules. There was little traffic on the other lanes to avoid boredom during the journey, enhance the speed feeling, suggest participants to stay on the rightmost lane to reduce variability in driving behaviours, and increase consistency in the traffic conditions they would encounter (Figure 1). Individuals were instructed to drive as they normally would, and also told there would be speed limits on overhead gantries.

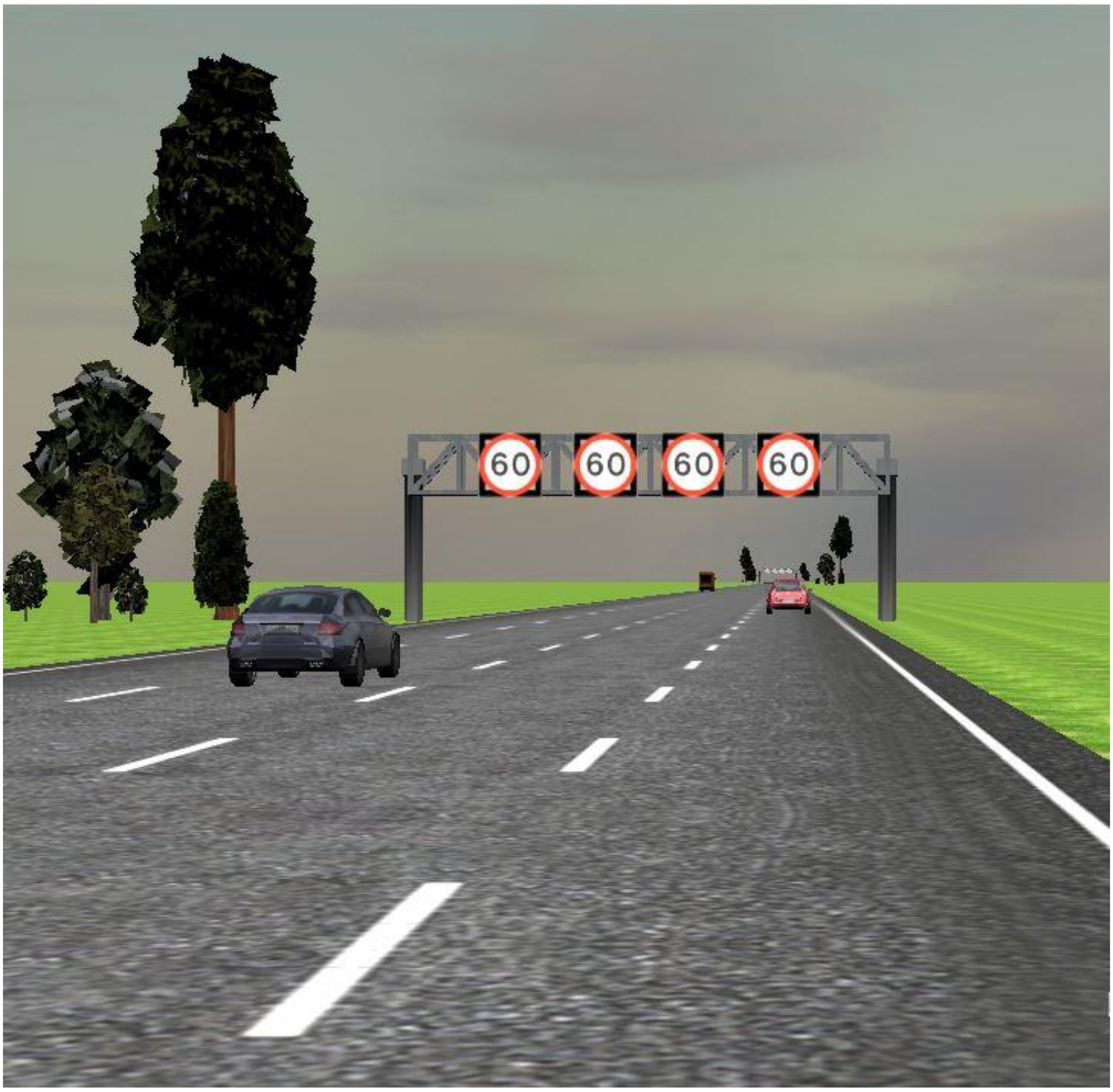


Figure 1. Illustration of the virtual road environment in the baseline noHMI condition.

Participants always started the study with the baseline condition followed by either one of the two experimental conditions. In both experimental conditions, they were told the speed limits would also be displayed on the mobile phone. The first speed limit in the baseline condition was different from the one in the experimental conditions to prevent a learning effect (Figures 2 and 3). The five following speed limits were similar in both experimental conditions to allow comparisons. Changes in speed limits were congruent with Highways Agency guidelines [12] and the British Highway Code, herein speed could either drop or increase by 10 miles successively. All of the speed limit warnings occurred on a straight section of the road to control for the driving conditions and associated driving demand (i.e., workload) between participants. The 70 VSL consisted of a white circle crossed by a diagonal black line.

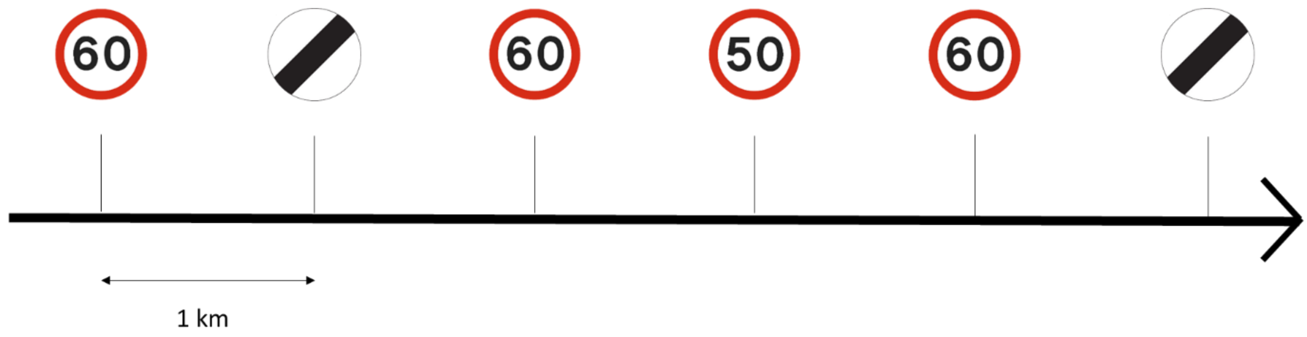


Figure 2. Position and order of overhead gantry's speed limits in the noHMI baseline condition. The white circle crossed by a diagonal line is the National Speed Limit sign, which is 70 mph.

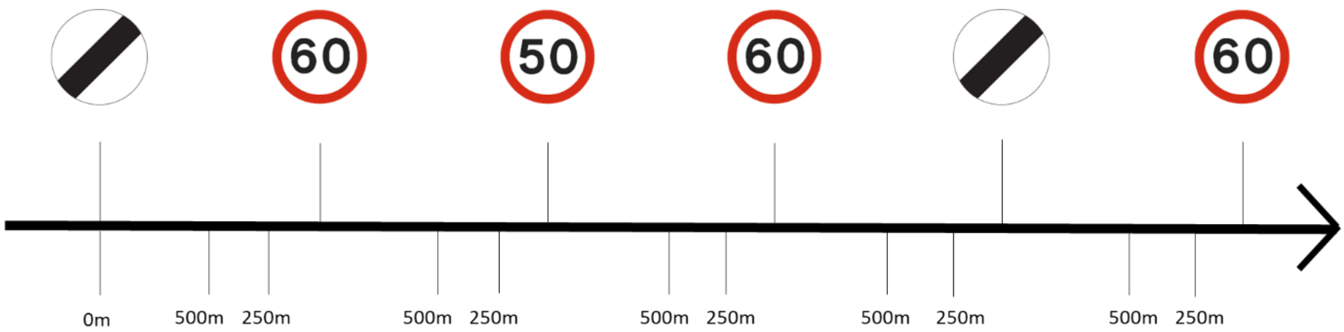


Figure 3. Position and order of the overhead gantry's speed limits in both experimental conditions (i.e., *trig250 m* & *trig500 m*). The triggers for the speed limits conveyed by the in-vehicle app are shown below the axis.

Finally, after this simulator run, participants answered questions about their experience with the in-vehicle app and socio-demographic variables. They were also debriefed to understand the purpose of the study and were given the opportunity to ask any question about the experience they just had in the driving simulator.

2.3. Participants

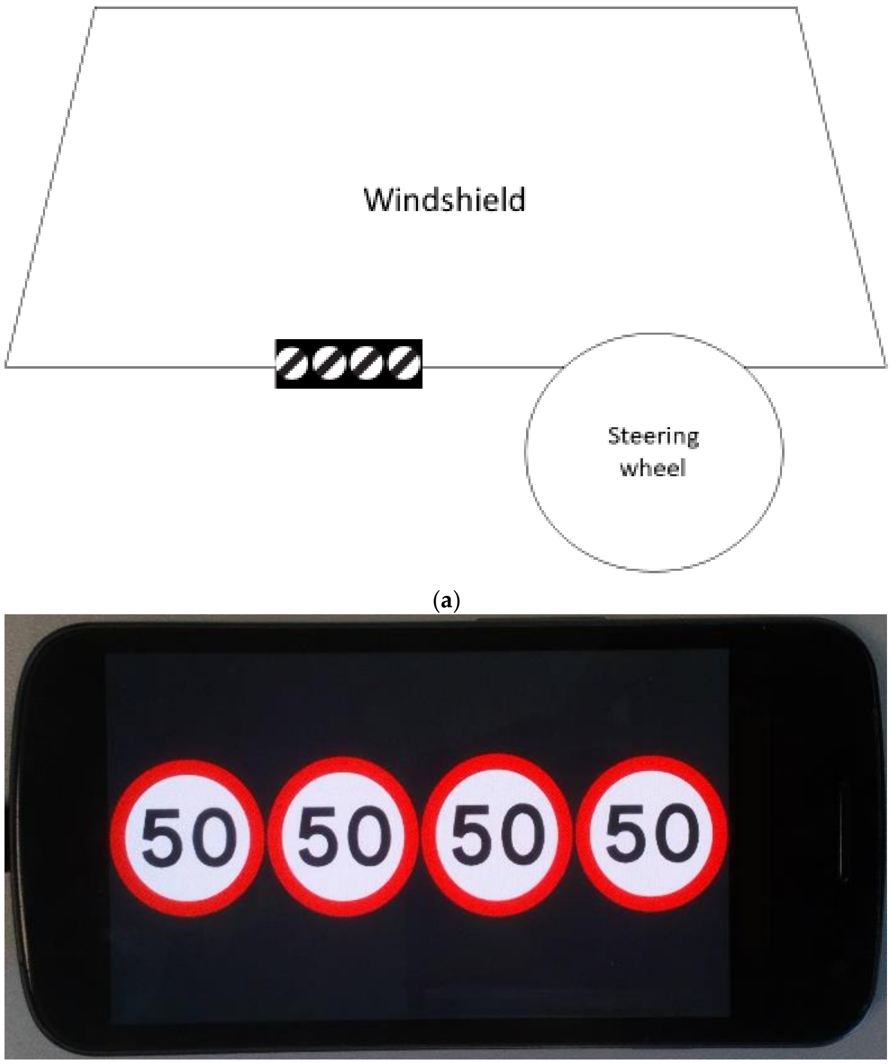
A convenience sample of 20 participants completed the experiment. They were recruited amongst Coventry University students and staff. Their ages varied from 21 to 50 years (M = 31.3, SD = 9.4) and both males (11) and females (9) participated. On average, participants held their driving licence for 12.4 years (SD = 8.4) and had driven over 4000 km (SD = 3932) in the past twelve months prior to the experiment. All participants reported normal or corrected to normal eyesight and received a 15 pounds voucher in compensation for their participation. They remained anonymous throughout the study and were free to withdraw at any time.

2.4. Simulator Equipment

The driving simulator consisted of a fixed-base car buck. A panoramic view was projected via three HD channels onto a 220° curved screen, with 5760 × 1080 px display resolution at a refresh rate of 60 Hz. The 10″ wing mirrors and 32″ rear view mirror fitted on the instrumented vehicle further allowed to simulate the driving environment. The driving simulation environment was designed with OpenDS 4.0. The steering wheel was equipped with a force feedback steering control unit, and the buck was equipped with two bass shakers, conveying physical vibrations through the car buck.

2.5. Human–Machine Interface

The visual HMI was shown in a mobile phone (size: 16:9; resolution: 720 × 1080 px). The mobile phone was displayed in landscape mode. It was located on the centre console (see Figure 4a). The four speed limit signs were displayed across the screen during 4 s, on a black background (see Figure 4b). The 4 s duration was determined on the 120 m minimum clear visibility distance for road signs on UK motorways with a speed limit of 70 mph (120 m/70 mph = 3.83 s; [13]). Four signs were displayed on the mobile phone at it replicates the overhead gantries present on UK's four-lane motorways, with one speed limit sign displayed above each lane. All the visual information was paired with the same acoustic signal (i.e., two pulses within 0.6 s, frequency of 250 Hz), which was designed to match the level 0 of urgency of the event, namely *information only* [14,15].



(**a**)

(**b**)

Figure 4. (**a**) Sketch of the HMI location with the national speed limit signs (i.e., 70 mph). (**b**) Illustration of the 50 pmh VSL displayed on the mobile phone.

3. Measures

3.1. Questionnaire

The first section of the questionnaire was composed of the System Usability Scale [16], followed by the system acceptance scale [17]. In order to understand the specificities of the in-vehicle app used in this study, the following bespoke questions on acceptance, including data-sharing, were asked in a randomised order (i.e., a 5-point Likert scale ranging from *1: Strongly disagree* to *5: Strongly agree*):

- I would mind if using an app that replaces the gantry and road signs every time I drive was mandatory,
- I would be happy if an app replaces the gantry and road signs,
- I would be happy if the driving-related data collected by my car was shared with other road users,
- I would be happy if the driving-related data collected by my car was shared with other parties (app and vehicle manufacturers, local transport authorities, traffic management).

Additional usability questions on the specificities of the app were asked to better understand how participants perceived the design and the location of the app:

- The warnings' location in the vehicle was appropriate;
- I would like to be told what the warnings mean before seeing them while driving;
- I had enough time to see the warnings on the mobile phone;
- I had been distracted by these warnings;
- I found the signs were congruent with what happened on the road.

Finally, the following socio-demographic information was asked: gender, age, driving experience and familiarity with managed motorways. A picture of the M42 in the UK was provided in case drivers were not familiar with this label.

3.2. Driving Behaviour

The first indicator was the vehicle mean speed measured for each participant, respectively, 250 m and 500 m before the overhead gantry. These two different road section lengths were congruent with the speed limit warnings displayed in the vehicle in both experimental conditions: *trig250 m* and *trig500 m*.

The second indicator was the speed at each of the gantries for each participant, measured when the center point of the vehicle was located right below the overhead gantry.

The third measure was the homogeneity in speed between subjects referred in the present paper as speed homogeneity. It is defined as the standard deviation of the average speed for all participants on a road section [1], and could be compared to speed consistency.

Statistical data from the simulator outputs were analysed by means of within-between model 2 (with and without HMI) $\times$ 2 (HMI distance-based trigger: *trig250 m* vs. *trig500 m*) ANOVAs. To assess whether age and driving behaviour were related (i.e., speed and speed homogeneity), Person correlation coefficient were calculated but no significant results were found. The software IBM SPSS Statistics 21 was used for the data analysis.

4. Results

4.1. Usability and Data-Sharing

Participants declared having enough time to see the signs on the mobile phone (*MIN* = 2, *MAX* = 5), the signs were sufficiently large (*MIN* = 3, *MAX* = 5), the signs (*MIN* = 1, *MAX* = 4) and the sounds were not very distractive (*MIN* = 1, *MAX* = 5), the sound was not very annoying (*MIN* = 1, *MAX* = 5), the sound volume was adequate (*MIN* = 2, *MAX* = 5), and eventually that the signs matched the situations that occurred on the road (*MIN* = 2, *MAX* = 5) (Figure 5).

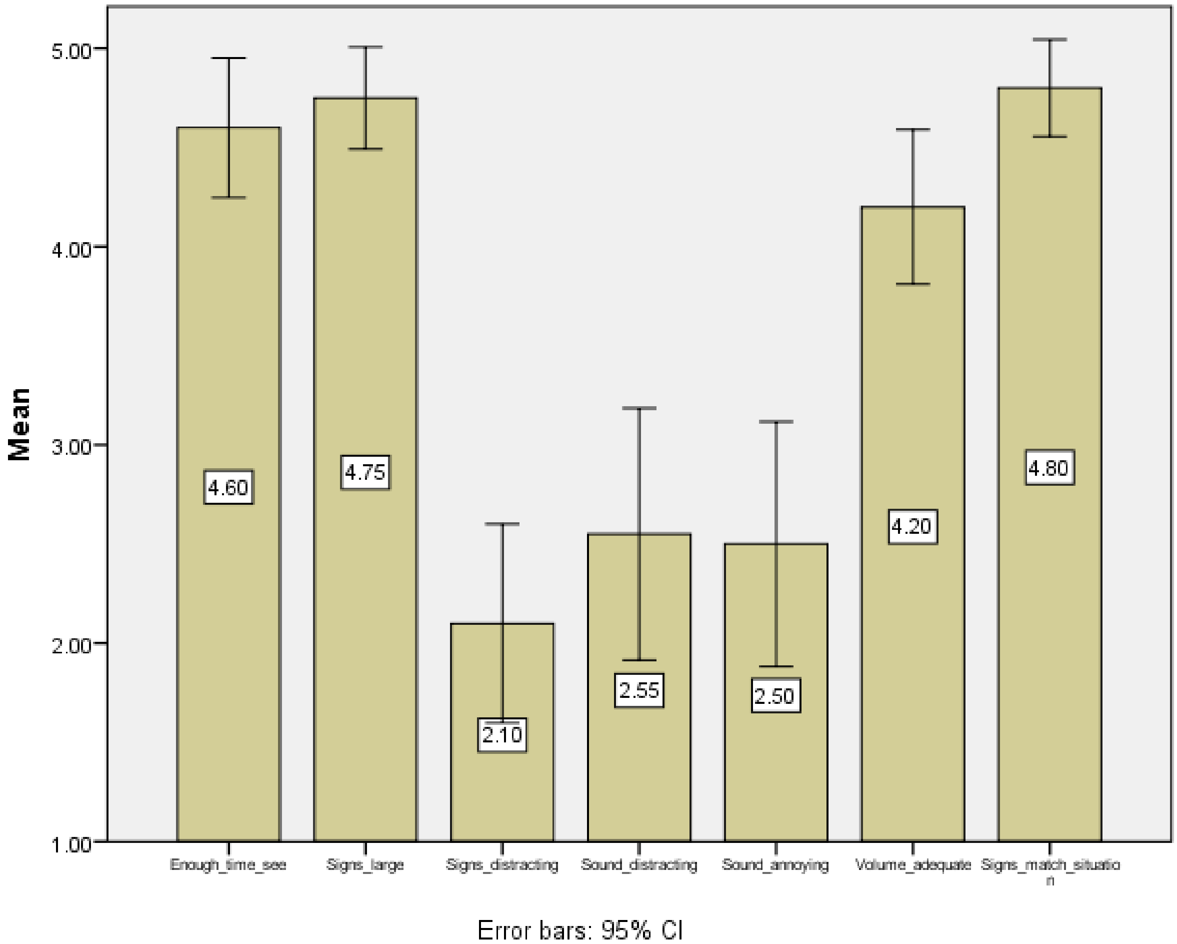


Figure 5. Descriptive statistics of the app usability. The *Y* axis shows the mean value whereas the different dimensions of usability are shown on the *X* axis.

The mean SUS score was 81.5 (n = 20, *SD* = 10.86, *MIN* = 62.5, *MAX* = 100), which could be interpreted as excellent according to the SUS adjective rating scale based on a meta-analysis including nearly 1000 SUS surveys [18]. The usefulness and satisfying scores of the system acceptance scale were 1.18 (*SD* = 0.76, *MIN* = 0, *MAX* = 2) and 0.49 (*SD* = 0.96, *MIN* = −1.75, *MAX* = 1.75), respectively. Both scores are reasonably good as the scale ranges from −2 to +2. Participants declared they would spend £3.05 on average to buy the application (*SD* = 3.02, *MIN* = 0, *MAX* = 10).

On average, participants declared they would not be happy if the gantry and the road signs were replaced by the application (*SD* = 1.2, *MIN* = 1, *MAX* = 5).

Regarding their own driving-related data, they declared they would be happy sharing it with other road users (*SD* = 1.5, *MIN* = 1, *MAX* = 5), but they would be less happy sharing it with other road parties (*SD* = 1.49, *MIN* = 1, *MAX* = 5) (Figure 6).

4.2. Speed Plots

The speed in km/h of all participants in each of the three conditions were plotted to illustrate the variations in speed over the section of the road that had the same speed limits, i.e., 70 mph (113 km/h)–60 mph (97 km/h)–50 mph (80 km/h)–60 mph (97 km/h)–70 mph (113 km/h) (Figure 7). Bonferroni post hoc correction was applied for within subjects comparisons.

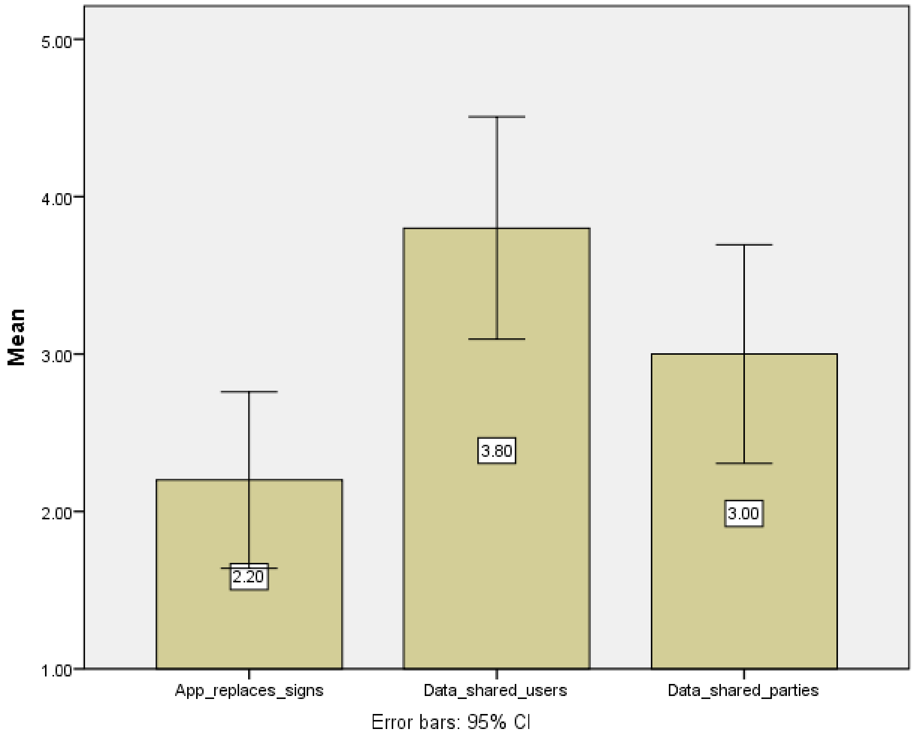


Figure 6. Descriptive statistics of the data-sharing related questions.

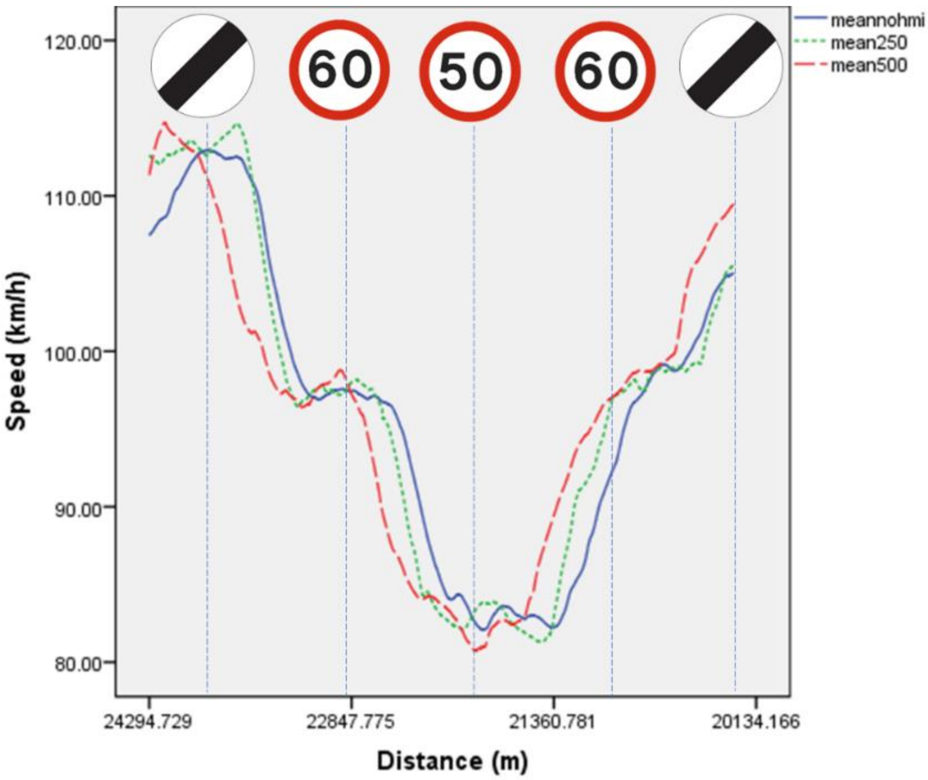


Figure 7. Plot of the mean speed in the noHMI condition (n = 20), the trig250 m condition (n = 10) and the trig500 m condition (n = 10). The locations of the overhead gantries are illustrated with the dashed vertical lines, representing the 70 mph, 60 mph, 50 mph, 60 mph and 70 mph overhead gantries, respectively.

4.3. Mean Speed Measured for 250 m and 500 m

All the following statistical tests were conducted on km/h values. The graphs indicate the speed value in mph to be congruent with the speed limits signs. None of the participants used the brakes to decelerate, they only used the engine deceleration. Partial eta squared values are presented in the different tables.

4.3.1. Baseline Condition: *noHMI*

This section described the different speed values observed amongst the within and between subjects factors. The aim was to see if there were any significant differences prior to participants' exposition to the in-vehicle speed limit warnings.

In the within subjects *noHMI* baseline condition, a MANOVA was performed repeated measures ANOVA were conducted to make comparisons between mean speeds measured for 500 m and 250 m before all the overhead gantries. No significant differences were observed (Table 2).

Table 2. Repeated measures ANOVA conducted to compare mean speeds within the baseline noHMI condition.

Gantry	*F*	*df*	*p* Value	$\eta_p{}^2$	*Distance to Gantry Measurement*	*Mean* *	*SD* *
70 mph (113 km/h)	2.95	1, 19	0.10	0.13	250 m 500 m	99.83 99.16	6.80 6.36
60 mph (97 km/h)	0.75	1, 19	0.75	0.01	250 m 500 m	110.52 110.61	4.89 4.51
50 mph (80 km/h)	0.97	1, 19	0.34	0.05	250 m 500 m	95.23 95.56	3.62 3.72
60 mph (97 km/h)	1.78	1, 19	0.20	0.09	250 m 500 m	82.65 82.33	5.06 4.86
70 mph (113 km/h)	1.70	1, 19	0.21	0.08	250 m 500 m	100.33 99.83	6.06 5.73

* Mean and SD values are reported in km/h.

Similarly, in the *noHMI* condition, ten between subjects ANOVA were conducted to compare differences with respect to mean speeds measured for 500 m and 250 m before the overhead gantries. No significant differences were found (Table 3). A MANOVA was also used to confirm these results, Pillai's Trace = 0.42, F = 0.66, df = (9), p = 0.74.

Table 3. Analysis of variance to test the mean speed of both experimental groups in the baseline noHMI condition.

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p* Value	$\eta_p{}^2$	*XP Condition*	*Mean* *	*SD* *
70 mph (113 km/h)	250 m	0.02	1, 18	0.883	0.00	trig250 m trig500 m	99.59 100.07	8.12 5.61
	500 m	0.00	1, 18	0.974	0.00	trig250 m trig500 m	99.12 99.21	7.71 5.09
60 mph (97 km/h)	250 m	3.81	1, 18	0.067	0.18	trig250 m trig500 m	108.52 112.52	5.59 3.23
	500 m	3.98	1, 18	0.061	0.18	trig250 m trig500 m	108.74 112.52	5.37 2.52
50 mph (80 km/h)	250 m	2.20	1, 18	0.156	0.11	trig250 m trig500 m	94.07 96.39	4.79 1.32
	500 m	2.98	1, 18	0.102	0.14	trig250 m trig500 m	94.19 96.93	4.68 1.79

Table 3. *Cont.*

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p* **Value**	$\eta_p{}^2$	*XP Condition*	*Mean **	*SD **
60 mph (97 km/h)	250 m	0.04	1, 18	0.841	0.00	trig250 m trig500 m	82.42 82.89	5.54 4.82
	500 m	0.02	1, 18	0.895	0.00	trig250 m trig500 m	82.48 82.18	5.93 3.83
70 mph (113 km/h)	250 m	0.55	1, 18	0.469	0.03	trig250 m trig500 m	101.34 99.32	6.25 6.01
	500 m	0.08	1, 18	0.778	0.01	trig250 m trig500 m	100.20 99.44	6.43 5.25

* Mean and SD values are reported in km/h.

4.3.2. Experimental Conditions: HMI

Within the *trig500 m* experimental group, five repeated measures ANOVA were conducted to make comparisons between mean speed measured for 500 m and 250 m before the overhead gantries. Significant differences were found for the five speed limit warnings in the *trig500 m* condition. Three significant differences were found within the *trig250 m* condition for the three 60 mph speed limits (Table 4). The two non-significant for the 50 mph and 70 mph gantries could be explained by the shorter delay between the in-vehicle speed limit warning and the overhead gantry.

Table 4. Repeated measures ANOVA conducted to compare mean speeds at 250 m and 500 before the overhead gantry, within both experimental conditions.

Gantry	*XP Condition*	*F*	*df*	*p* **Value**	$\eta_p{}^2$	*Distance to Gantry Measurement*	*Mean **	*SD **
60 mph (97 km/h)	trig250 m	26.51	1, 9	0.001	0.75	250 m 500 m	109.93 101.31	3.46 3.04
	trig500 m	23.56	1, 9	0.001	0.72	250 m 500 m	101.74 104.28	5.77 5.33
50 mph (80 km/h)	trig250 m	2.04	1, 9	0.187	0.19	250 m 500 m	91.04 91.04	4.48 4.48
	trig500 m	19.11	1, 9	0.002	0.68	250 m 500 m	86.51 89.03	4.58 3.27
60 mph (97 km/h)	trig250 m	12.74	1, 9	0.006	0.59	250 m 500 m	84.65 83.04	3.49 3.10
	trig500 m	13.97	1, 9	0.005	0.61	250 m 500 m	90.82 87.78	5.80 5.00
70 mph (113 km/h)	trig250 m	0.003	1, 9	0.956	0.00	250 m 500 m	97.60 97.54	5.82 6.22
	trig500 m	9.25	1, 9	0.014	0.51	250 m 500 m	106.37 104.32	7.70 6.69
60 mph (97 km/h)	trig250 m	39.94	1, 9	0.000	0.82	250 m 500 m	109.68 112.38	3.71 2.98
	trig500 m	45.36	1, 9	0.000	0.83	250 m 500 m	101.10 105.44	5.19 5.02

* Mean and SD values are reported in km/h.

There were statistically significant differences between the two experimental groups, *trig250 m* and *trig500 m*, for the five gantries as determined by the one-way ANOVA (Table 5). Descriptive statistics showed two patterns. First, when the speed limit dropped by 10 mph (16.09 km/h), participants from the *trig250 m* condition had higher mean speeds compared to those from the *trig500 m* condition. Second, when the speed limit increased by 10 mph, participants from the *trig250 m* condition had lower mean speeds compared to those from the *trig500 m* condition. These mean speed values were measured for 250 m and 500 m before the overhead gantry.

Table 5. Analysis of variance to test the effect of the HMI trigger on mean speed values. Scores reported in km/h.

Gantry	*XP Condition*	*F*	*df*	*p* Value	$\eta_p{}^2$	*Distance to Gantry Measurement*	*Mean **	*SD **
60 mph (97 km/h)	trig250 m	14.8	1, 18	0.001	0.45	250 m 500 m	109.93 101.74	3.46 5.77
	trig500 m	13.11	1, 18	0.002	0.42	250 m 500 m	111.31 104.28	3.04 5.33
50 mph (80 km/h)	trig250 m	5.0	1, 18	0.038	0.22	250 m 500 m	91.04 86.51	4.48 4.58
	trig500 m	6.16	1, 18	0.023	0.26	250 m 500 m	92.33 89.03	2.64 3.27
60 mph (97 km/h)	trig250 m	8.29	1, 18	0.010	0.32	250 m 500 m	84.65 90.82	3.49 5.80
	trig500 m	6.51	1, 18	0.020	0.27	250 m 500 m	83.04 87.78	3.10 5.00
70 mph (113 km/h)	trig250 m	8.26	1, 18	0.010	0.32	250 m 500 m	97.60 106.37	5.82 7.70
	trig500 m	5.52	1, 18	0.030	0.24	250 m 500 m	97.54 104.32	6.22 6.69
60 mph (97 km/h)	trig250 m	18.10	1, 18	0.000	0.50	250 m 500 m	109.68 101.10	3.71 5.19
	trig500 m	14.12	1, 18	0.001	0.44	250 m 500 m	112.38 105.44	2.98 5.02

* Mean and SD values are reported in km/h.

A graphical representation of the mean speeds in the baseline condition (*noHMI*) and both experimental conditions (*trig250 m* or *trig500 m*) summed up the aforementioned results, and showed four interactions: two between groups and another two within groups (Figure 8).

A total of sixteen repeated measures ANOVA were conducted to determine if there were any significant differences between the speed measured for 250 m and 500 m between the experimental conditions for the two similar sequences of gantry present in both the baseline and the experimental condition, i.e., 60 mph–50 mph–60 mph and 70 mph. No significant differences were found between the *noHMI* and the *trig250 m* condition for any of the gantries (Table 6). On the contrary, significant differences were found between the *noHMI* and the *trig500 m* condition for all gantries (Table 7). When speed dropped by 10 mph, the mean speed was significantly higher in the *noHMI* condition than in the *trig500 m* condition. However, when speed increased, the mean speed was significantly lower in the *noHMI* condition than in the *trig500 m* condition. This pattern was illustrated in Figure 8.

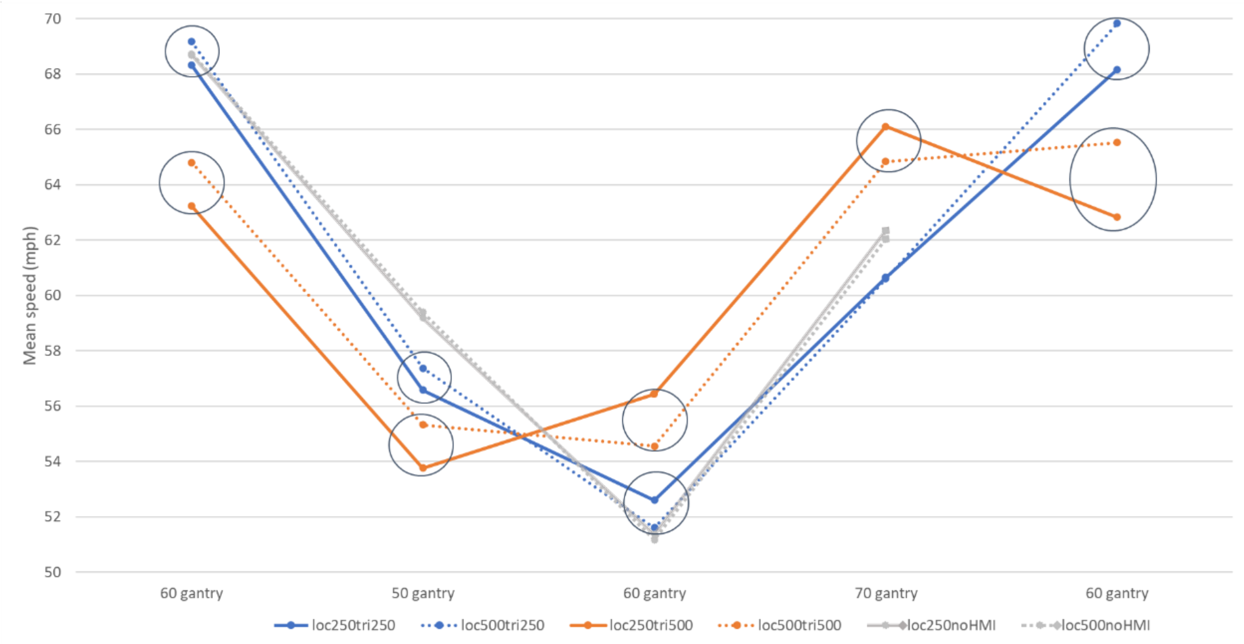


Figure 8. Graphical representation of the mean speeds (mph) in both experimental conditions. Plain lines represent the trig250 m and the noHMI condition whereas dashed lines represent the trig500 m condition. Blues lines represent the trig250 m condition, orange lines the trig500 m condition and the grey lines the noHMI condition. Significant differences within the same HMI trigger condition are circled.

Table 6. Repeated measures ANOVA conducted to compare mean speeds between the noHMI and the trig250 m conditions for the same sequence of gantries. Scores reported in km/h.

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p* **Value**	$\eta_p{}^2$	*XP Condition*	*Mean* *	*SD* *
60 mph (97 km/h)	250 m	0.838	1, 9	0.384	0.09	noHMI trig250 m	108.53 109.93	5.60 3.46
	500 m	32.95	1, 9	0.136	0.23	noHMI trig250 m	108.74 111.31	5.37 3.04
50 mph (80 km/h)	250 m	2.87	1, 9	0.124	0.24	noHMI trig250 m	94.07 91.04	4.79 4.48
	500 m	1.21	1, 9	0.299	0.12	noHMI trig250 m	94.20 92.33	4.68 2.64
60 mph (97 km/h)	250 m	1.41	1, 9	0.264	0.14	noHMI trig250 m	82.42 84.65	5.54 3.49
	500 m	0.11	1, 9	0.751	0.01	noHMI trig250 m	82.49 83.04	5.93 3.10
70 mph (113 km/h)	250 m	1.83	1, 9	0.203	0.17	noHMI trig250 m	101.35 97.60	6.25 5.82
	500 m	0.65	1, 9	0.442	0.07	noHMI trig250 m	100.20 97.53	6.43 6.22

* Mean and SD values are reported in km/h.

Table 7. Repeated measures ANOVA conducted to compare mean speeds between the noHMI and the trig500 m conditions for the same sequence of gantries. Scores reported in km/h.

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p* Value	$\eta_p{}^2$	*XP Condition*	*Mean* *	*SD* *
60 mph (97 km/h)	250 m	32.62	1, 9	0.000	0.78	noHMI trig500 m	112.52 101.74	3.24 5.77
	500 m	18.85	1, 9	0.002	0.68	noHMI trig500 m	112.49 104.28	2.53 5.33
50 mph (80 km/h)	250 m	49.99	1, 9	0.000	0.85	noHMI trig500 m	96.40 86.51	1.32 4.58
	500 m	48.41	1, 9	0.000	0.84	noHMI trig500 m	96.93 89.03	1.79 3.27
60 mph (97 km/h)	250 m	18.82	1, 9	0.002	0.68	noHMI trig500 m	82.90 90.82	4.82 5.79
	500 m	25.64	1, 9	0.001	0.74	noHMI trig500 m	82.19 87.78	3.83 4.99
70 mph (113 km/h)	250 m	10.13	1, 9	0.011	0.53	noHMI trig500 m	99.32 106.37	6.01 7.70
	500 m	8.35	1, 9	0.018	0.48	noHMI trig500 m	99.45 104.32	5.26 6.69

* Mean and SD values are reported in km/h.

4.4. Speed at Gantry

Regarding participants' vehicle speed at the gantry (i.e., the central point of the vehicle was below the gantry), there were statistically significant differences between the *trig250 m* (n = 10) and *trig500 m* groups (n = 10) for the five gantries as determined by the one-way ANOVA (Table 8).

Table 8. Analysis of variance to compare the speed at each gantry between both experimental groups.

Gantry	*F*	*df*	*p* Value	$\eta_p{}^2$	*XP Condition*	*Mean* *	*SD* *
60 mph (97 km/h)	11.66	1, 18	0.003	0.39	trig250 m trig500 m	103.27 96.69	5.09 3.34
50 mph (80 km/h)	5.36	1, 18	0.033	0.23	trig250 m trig500 m	90.40 82.33	10.11 4.41
60 mph (97 km/h)	10.84	1, 18	0.004	0.38	trig250 m trig500 m	87.75 95.17	4.55 5.50
70 mph (113 km/h)	9.87	1, 18	0.006	0.35	trig250 m trig500 m	97.77 106.90	5.04 8.47
60 mph (97 km/h)	7.39	1, 18	0.14	0.29	trig250 m trig500 m	105.43 98.66	6.50 4.44

* Mean and SD values are reported in km/h.

Descriptive statistics showed two patterns (see Figure 9). First, when the speed limits dropped by 10 mph, participants from the *trig250 m* condition had higher speeds at the overhead gantry than those from the *trig500 m* condition. Second, when the speed limit increased by 10 mph, participants from the *trig250 m* condition had lower mean speeds compared to those from the *trig500 m* condition.

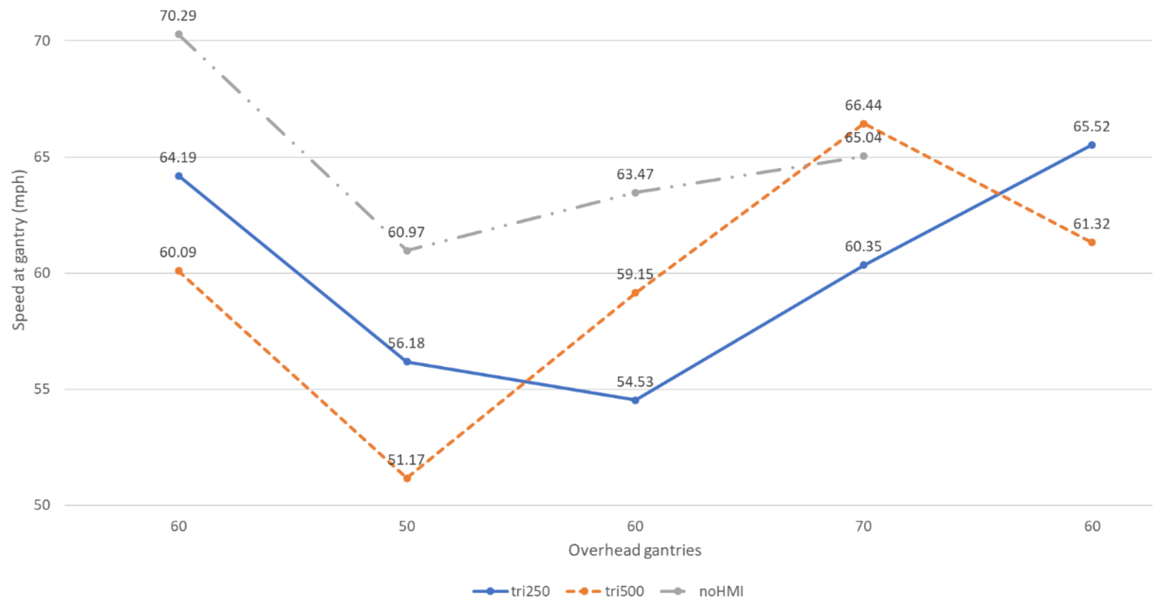


Figure 9. Graphical representation of the speed (mph) at each overhand gantry in the noHMI condition and both experimental conditions. Blue plain line represents the trig250 m (n = 10) condition, the orange dashed line the trig500 m condition (n = 10), and the grey mix plain-dashed line the noHMI condition (n = 20).

Eight repeated measures ANOVA were conducted to determine if there were any significant differences between all the conditions with regard to the speed at gantry for the two similar sequences of speed limit gantries present in the baseline and the experimental conditions, i.e., 60 mph–50 mph–60 mph and 70 mph (Table 9). Results showed significant differences in the speed at gantry between most conditions. In the *trig250 m* condition, speed was on average 8.93 km/h lower than the *noHMI* condition, whereas in the *trig500 m* condition speed was 11.84 km/h lower than the *noHMI* condition. However, no significant differences were found at the 50 mph gantry between the *noHMI* and the *trig250 m* condition, although the speed is 4 km/h higher the *noHMI* than in the *trig250 m* condition. Regarding the 70 mph gantry, no significant differences were found between the *noHMI* and the *trig500 m* conditions.

Table 9. Repeated measures ANOVA conducted to compare speed at gantry between the noHMI and the HMI conditions (i.e., trig250 m and trig500 m) for the same sequence of gantries.

Gantry	*HMI trigger Distance to Gantry*	*F*	*df*	*p* **Value**	$\eta_p{}^2$	*XP Condition*	*Mean **	*SD **
60 mph (97 km/h)	250 m	12.09	1, 9	0.007	0.57	noHMI trig250 m	113.37 103.27	6.84 5.09
	500 m	395.02	1, 9	0.000	0.98	noHMI trig500 m	114.81 96.70	2.26 3.34
50 mph (80 km/h)	250 m	3.24	1, 9	0.105	0.26	noHMI trig250 m	96.39 90.4	5.65 10.10
	500 m	70.38	1, 9	0.000	0.89	noHMI trig500 m	99.71 82.33	3.61 4.41
60 mph (97 km/h)	250 m	69.42	1, 9	0.000	0.89	noHMI trig250 m	99.65 87.74	2.41 4.55
	500 m	32.96	1, 9	0.000	0.79	noHMI trig500 m	104.61 95.17	2.25 5.50

Table 9. *Cont.*

Gantry	*HMI trigger Distance to Gantry*	*F*	*df*	*p* **Value**	η_p^2	*XP Condition*	*Mean **	*SD **
70 mph (113 km/h)	250 m	17.64	1, 9	0.002	0.66	noHMI trig250 m	104.82 97.11	3.30 5.04
	500 m	1.29	1, 9	0.289	0.12	noHMI trig500 m	104.49 106.90	5.50 8.47

* Mean and SD values are reported in km/h.

4.5. Speed Homogeneity

4.5.1. Baseline Condition: *noHMI*

This section described the different speed homogeneity values observed amongst the within and between subjects factors. Speed homogeneity is the standard deviation of the average speed for all participants on a road section (i.e., more consistent speeds). The aim was to see if there were any significant differences prior to participants' exposition to the in-vehicle speed limits warnings.

In the within subjects *noHMI* baseline condition, repeated measures ANOVA were conducted to make comparisons between speed homogeneity measured for 500 m and 250 m before all the overhead gantries. No significant differences were observed for any of the overhead gantries (Table 10).

Table 10. Repeated measures ANOVA conducted to compare mean speed homogeneity within the baseline noHMI condition.

Gantry	*F*	*df*	*p* **Value**	η_p^2	*Distance to Gantry Measurement*	*Mean **	*SD **
70 mph (113 km/h)	2.25	1, 19	0.15	0.11	250 m 500 m	2.68 2.99	1.39 1.45
60 mph (97 km/h)	1.01	1, 19	0.33	0.05	250 m 500 m	1.69 1.95	0.82 0.73
50 mph (80 km/h)	2.16	1, 19	0.16	0.10	250 m 500 m	1.63 1.96	0.73 0.70
60 mph (97 km/h)	1.53	1, 19	0.23	0.07	250 m 500 m	1.07 1.38	0.79 1.18
70 mph (113 km/h)	1.85	1, 19	0.19	0.09	250 m 500 m	1.99 2.39	1.27 1.36

* Mean and SD values are reported in km/h.

Similarly, ten between subjects ANOVA were conducted to compare any difference between speed homogeneity measured for 500 m and 250 m before the overhead gantries in the baseline *noHMI* condition. No significant differences were found (Table 11).

Table 11. Analysis of variance to test the mean speed homogeneity of both groups in the noHMI baseline condition.

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p* **Value**	η_p^2	*XP Condition*	*Mean **	*SD **
70 mph (113 km/h)	250 m	0.33	1, 18	0.574	0.02	trig250 m trig500 m	2.86 2.50	1.53 1.30
	500 m	0.26	1, 18	0.615	0.01	trig250 m trig500 m	3.17 2.83	1.81 1.03

Table 11. *Cont.*

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p* **Value**	$\eta_p{}^2$	*XP Condition*	*Mean **	*SD **
60 mph (97 km/h)	250 m	0.01	1, 18	0.913	0.00	trig250 m trig500 m	1.67 1.71	0.77 0.92
	500 m	1.69	1, 18	0.211	0.09	trig250 m trig500 m	2.16 1.74	0.84 0.57
50 mph (80 km/h)	250 m	0.17	1, 18	0.687	0.01	trig250 m trig500 m	1.70 1.57	0.91 0.54
	500 m	.03	1, 18	0.862	0.00	trig250 m trig500 m	1.93 1.99	0.32 0.97
60 mph (97 km/h)	250 m	1.42	1, 18	0.250	0.07	trig250 m trig500 m	1.28 0.86	0.88 0.68
	500 m	0.30	1, 18	0.594	0.02	trig250 m trig500 m	1.53 1.24	1.25 1.14
70 mph (113 km/h)	250 m	0.88	1, 18	0.360	0.05	trig250 m trig500 m	2.25 1.72	1.30 1.26
	t500 m	.17	1, 18	0.690	0.01	trig250 m trig500 m	2.52 2.26	1.65 1.06

* Mean and SD values are reported in km/h.

4.5.2. Experimental Conditions: HMI

A total of ten ANOVA were conducted to make comparisons between mean SD scores measured for 500 m and 250 m before the overhead gantries in both experimental conditions (Table 12). Results showed significant differences only for the *trig250 m* condition, and for all the overhead gantries. Within that condition, mean SD scores are higher when measured over 250 m than 500 m before the overhead gantry, meaning that speed homogeneity was greater in the *trig500 m* condition.

Table 12. Analysis of variance to test the effect of the HMI trigger on speed homogeneity.

Gantry	*XP Condition*	*F*	*df*	*p* **Value**	$\eta_p{}^2$	*Distance to Gantry Measurement*	*Mean **	*SD **
60 mph (97 km/h)	trig250 m	12.33	1, 18	0.002	0.41	250 m 500 m	3.73 2.12	1.10 0.93
	trig500 m	3.77	1, 18	0.081	0.16	250 m 500 m	3.24 4.11	0.95 1.14
50 mph (80 km/h)	trig250 m	8.51	1, 18	0.004	0.36	250 m 500 m	3.29 1.99	1.04 0.71
	trig500 m	0.02	1, 18	0.923	0.00	250 m 500 m	4.32 4.26	1.50 1.48
60 mph (97 km/h)	trig250 m	15.21	1, 18	0.025	0.25	250 m 500 m	4.35 2.60	1.97 1.10
	trig500 m	1.88	1, 18	0.51	0.02	250 m 500 m	4.06 4.67	1.63 2.38
70 mph (113 km/h)	trig250 m	15.86	1, 18	0.007	0.34	250 m 500 m	3.23 1.45	1.58 0.98
	trig500 m	6.33	1, 18	0.196	0.09	250 m 500 m	4.06 2.93	1.88 1.86
60 mph (97 km/h)	trig250 m	16.13	1, 18	0.018	0.28	250 m 500 m	3.70 1.90	1.87 1.11
	trig500 m	4.15	1, 18	0.333	0.05	250 m 500 m	3.60 4.51	1.83 2.24

* Mean and SD values are reported in km/h.

A graphical representation of speed homogeneity in both experimental conditions measured for 250 m and 500 m is shown in Figure 10. In the *250 m* condition, patterns were similar whereas in the *trig500 m* they were not following the same trend.

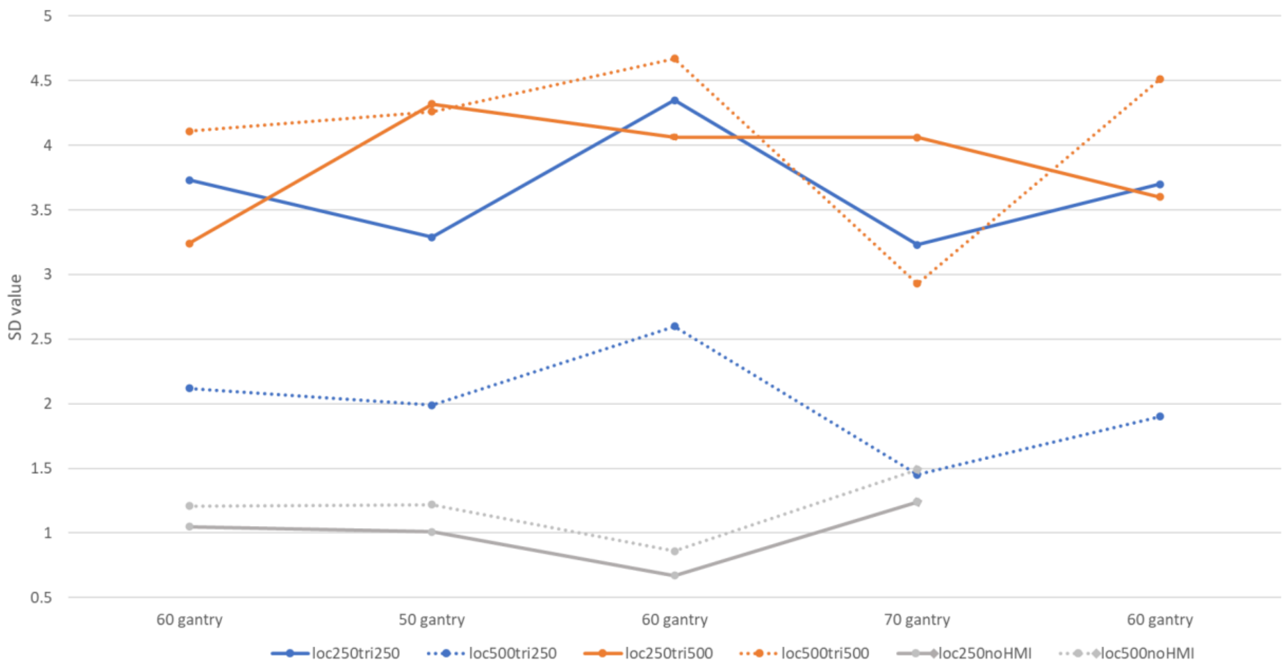


Figure 10. Graphical representation of the speed homogeneity (mph) in both experimental conditions. Plain lines represent the trig250 m and the noHMI conditions whereas dashed lines represent the trig500 m condition. Blues lines represent the trig250 m condition, orange lines the trig500 m condition and the grey lines the noHMI condition.

A total of sixteen repeated measures ANOVA were conducted to determine if there were any significant differences between the mean SD scores measured for 250 m and 500 m in both conditions for the two similar sequences of gantry present in the baseline and the experimental condition, i.e., 60 mph–50 mph–60 mph and 70 mph. No significant differences were found between the *noHMI* and the *trig250 m* condition for the 70 mph gantry only (Table 13). The three other gantries showed significant differences in speed homogeneity between the *noHMI* and the *trig250 m* conditions. The SD scores were always lower in the *noHMI* condition.

Table 13. Repeated measures ANOVA conducted to compare speed homogeneity between the noHMI and the trig250 m condition for the same sequence of gantries. Scores reported in km/h.

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p Value*	$\eta_p{}^2$	*XP Condition*	*Mean SD Score **
60 mph (97 km/h)	250 m	34.58	1, 9	0.000	0.79	noHMI trig250 m	1.67 3.73
	500 m	29.18	1, 9	0.000	0.76	noHMI trig250 m	1.74 4.11
50 mph (80 km/h)	250 m	11.77	1, 9	0.008	0.57	noHMI trig250 m	1.70 3.29
	500 m	22.17	1, 9	0.001	0.71	noHMI trig250 m	1.93 4.32

Table 13. *Cont.*

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p Value*	η_p^2	*XP Condition*	*Mean SD Score **
60 mph (97 km/h)	250 m	27.13	1, 9	0.001	0.75	noHMI trig250 m	1.28 4.35
	500 m	31.90	1, 9	0.005	0.61	noHMI trig250 m	1.53 4.06
70 mph (113 km/h)	250 m	2.01	1, 9	0.19	0.18	noHMI trig250 m	2.25 3.23
	500 m	3.24	1, 9	0.11	0.27	noHMI trig250 m	2.52 4.06

* Mean SD scores are reported in km/h

Regarding the *trig500 m* condition, results showed significant differences when speed was measured over 500 m for the 60 mph and 50 mph gantries, and only once for the second 60 mph gantry when speed was measured over 250 m (Table 14). Speed homogeneity was always lower in the *noHMI* condition than in the *trig500 m* condition. Similarly with the *trig250 m* condition, no significant differences in the SD scores were found for the 70 mph gantry between conditions.

Table 14. Repeated measures ANOVA conducted to compare speed homogeneity between the noHMI and the trig500 m condition for the same sequence of gantries. Scores reported in km/h.

Gantry	*Distance to Gantry Measurement*	*F*	*df*	*p Value*	η_p^2	*XP Condition*	*Mean SD Score **
60 mph (97 km/h)	250 m	0.83	1, 9	0.387	0.08	noHMI trig500 m	1.72 2.12
	500 m	29.18	1, 9	0.000	0.76	noHMI trig500 m	1.74 4.11
50 mph (80 km/h)	250 m	2.43	1, 9	0.153	0.21	noHMI trig500 m	1.57 1.99
	500 m	16.13	1, 9	0.003	0.64	noHMI trig500 m	1.99 4.26
60 mph (97 km/h)	250 m	12.17	1, 9	0.007	0.58	noHMI trig500 m	0.86 2.60
	500 m	10.26	1, 9	0.011	0.53	noHMI trig500 m	1.24 4.67
70 mph (113 km/h)	250 m	0.26	1, 9	0.622	0.03	noHMI trig500 m	1.71 1.45
	500 m	0.71	1, 9	0.419	0.07	noHMI trig500 m	2.27 2.93

* Mean SD scores are reported in km/h.

5. Discussion

A novel result found in this study is that, although the VSL app was considered usable and accepted by the participants, they declared they would not be keen on such an app replacing the existing gantry and road signs. Additional in-vehicle warnings may still be perceived as a help rather than a mandatory feature. More generally, it could be that Advanced Driver-Assistance Systems are not the panacea for all road safety ills and that drivers rely on their skill and experience first and foremost. Using a mobile phone to display road signs may not be very convenient considering drivers have to make sure it is charged at all time. An embedded display may remedy this, as it would be better integrated within the vehicle and would allow the icons displayed to be bigger and more visible. Network coverage might be another drawback making mobile phones less reliable than road signs and gantry [19]. Furthermore, participants seemed to be concerned about data sharing since they were reluctant to share it with anyone else but other road users.

Drivers were compliant with VSL which was congruent with previous driving simulator research using overhead gantries on a motorway [2,3] and in line with local regulation [12]. One explanation supporting compliance could be the frequency of the VSL [2], as participants in the HMI condition were exposed to both the in-vehicle warning and the overhead gantry. Drivers also complied with the VSL coupled with an in-vehicle warning duplicating the overhead gantry which is congruent with previous studies [7,20].

Driving behaviour patterns depended on whether vehicles accelerated or decelerated. The sooner the VSL, the lower the speed at the gantry when speed dropped. On the contrary, the sooner the VSL, the higher the speed at the gantry when speed increased. Similar results were observed for the mean speed measured over 250 m and 500 m before the gantry, respectively. The in-vehicle information seemed to increase situation awareness as drivers reacted more rapidly to speed limits. Another explanation could be that participant anticipated the change in speed earlier, due to the relatively high frequencies of VSL. Further studies could support these assumptions by using eye tracking data to understand which of the overhead gantry or the app drivers first look at.

Speed at the gantry was on average significantly lower in both *HMI* conditions than in the *noHMI* condition. Consequently, in both *HMI* conditions, speed at the gantry was closer to the mandatory limit than in the *noHMI* condition. It seems the in-vehicle app could help reduce speed as participants drove slower with respect to the overhead gantry location on the motorway. Besides, no significant difference was observed regarding speed at gantry between the *noHMI* and the *trig500 m* conditions for the 70 VSL speed limit gantry (i.e., national speed limit). This sign was probably more easily recognizable and conspicuous than the others from a further distance. The 70 VSL consisted of a white circle crossed by a diagonal black line which was different from the 50 and 60 VSL designs. As a result, displaying this sign upstream did not seem to improve the first level of situation awareness, namely perception. Given that the *trig250 m* participants had a lower speed of 7.7 km/h (i.e., 4.8 mph) on average at that 70 gantry compared with the *no HMI* condition, it could be considered that drivers were waiting for the speed limit to be displayed to start accelerating. This later result could support drivers' complacency towards the app.

Speed homogeneity was significantly lower when measured over 250 m before all gantries than over 500 m in the *trig250 m* condition. This result could be supported by drivers' complacency with the mobile phone warning. Indeed, drivers may have waited to perceive the warning to either start slowing down or accelerating. Thus, participants may have to compensate this short notice with a more erratic, sudden speed change. No differences in speed homogeneity were observed for the 70 mph gantries in the *trig500 m* condition, which could also be supported by the better visibility of the sign from a further distance. Indeed, the 70 mph sign design differ in terms of colour and content as shown in Figures 4 and 5, and there is no need to read the figure compared to the 60 mph and 50 mph signs. In addition, speed homogeneity was higher when no warnings were displayed in the vehicle, regardless the experimental condition. Again, no significant differences in the speed homogeneity scores at the 70 mph gantry were observed between the *noHMI* and both experimental conditions. Displaying in-vehicle VSL warning with a short notice resulted in less consistent longitudinal control, which could affect negatively safety and traffic fluidity. This is a new contribution of this study as this result was not in line with previous findings from driving simulator [5,21] and on-road [22] studies that showed drivers exposed to VSL signs usually drove with less variation and at uniform speed. However, in the present study, the VSL was displayed within the vehicle and on the road, whereas VSL was displayed via only one modality in the aforementioned studies.

Further investigation is required to understand the impact of in-vehicle VSL on driving behaviour using different distances from the road gantry. For instance, triggering the warning from a further distance (e.g., 1 km) or at the gantry may result in different driving behaviours and usability evaluations. Drivers' situation awareness, especially the projection level, could vary as individuals would have more time to anticipate the change in speed. Triggering the in-vehicle VSL a long distance before the gantry might also confuse drivers as the delay between the warning and the expected change in speed becomes longer. The exposition to various events and warnings occurring in the meantime may also contribute to drivers' confusion. Although the app was not considered very distractive, which is in line with previous research [7,20], and showed very good usability and acceptance scores, drivers' workload was not directly assessed. The duplication of information may increase workload. Eye tracking data such as gaze behaviour and eyes off road would also help understand objectively whether the in-vehicle information was distracting and increased workload.

It is to be noted that complacency with the app may be explained by the congruency between the content and the way information was displayed on both the phone app and the overhead gantry. Another explanation could be demand characteristics, an experimental artefact where participants adapt their behaviour to match what they expect the experimenter wants to observe [23].

Caution is necessary concerning the external validity of the present study. There was no specific reason to either decrease or increase speed limits in the context of this driving simulation. Besides, although drivers were free to change lane, the traffic on the left lanes was meant to incite them to stay on the rightmost lane. Another limitation of the present study is that a larger sample size would have helped reducing the probability of a type I error, especially for the between-subject factor *trigger*. Although the sample size is relatively small, most results observed in the present experiment are in line with previous research of a similar nature, which indicates the conclusions are reasonable and credible. Finally, participants involved in the study were fairly young and not very experienced, which might not be representative of the overall population of drivers at the time of the study in the UK.

Traffic simulation research suggested that possible traffic disruptions were likely to occur if all vehicles were not equipped with similar in-vehicle warning feature. System penetration models could help predict the effect of in-vehicle information on traffic on a broader scale. It could affect traffic in regard to system penetration rate and traffic condition [24]. For instance, lower penetration levels were followed by worse traffic performance compared to not having the information system at all. Furthermore, congestion significantly decreased the effects of the system due to restricted speed choice. Eventually, using the in-vehicle system resulted in smoother speed decelerations when approaching incidents. In addition to traffic simulation and driving simulation studies, on-road trials may help understand the potential and limits of additional safety related in-vehicle information, especially in low-visibility conditions such as fog, rain and during night-time. Road safety campaigns and driver training programmes should mention that, while in-vehicle information could be useful and draw the attention on important messages, drivers' attention needs to be directed to the road in priority to avoid distraction.

6. Conclusions

In-vehicle VSL has the potential to impact traffic and road safety, either positively or negatively. Results from the present driving simulator study supported previous findings suggesting that drivers were generally compliant with VSL, but also with additional in-vehicle VSL. As a result, drivers were more compliant with the overhead gantry speed limits. Sign design seemed to be impactful since the more recognizable the signs were on the road, the less compliant with the app drivers were. However, road gantry has priority over such additional features and caution is advised. With respect to speed homogeneity, too much complacency may lead to more erratic driving behaviour when the timing between the warning on the mobile phone and the VSL on the overhead gantry is short. This may well result in safety issues as the vehicular longitudinal control is more variable.

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References

1. Van Nes, N.; Brandenburg, S.; Twisk, D. Improving homogeneity by dynamic speed limit systems. *Accid. Anal. Prev.* **2010**, *42*, 944–952. [CrossRef] [PubMed]
2. Hoogendoorn, R.; Harms, I.; Hoogendoorn, S.; Brookhuis, K. Dynamic maximum speed limits: Perception, mental workload, and compliance. *Transp. Res. Rec. J. Transp. Res. Board* **2012**, *2321*, 46–54. [CrossRef]
3. Chang, C.-Y.; Li, C.-C. Visual and operational impacts of variable speed limit signs on bus drivers on freeways using driving simulator. In Proceedings of the 3rd IEEE Asia-Pacific Services Computing Conference (APSCC 2008), Yilan, Taiwan, 9–12 December 2008; pp. 1453–1458. [CrossRef]
4. Harms, I.M.; Brookhuis, K.A. Dynamic traffic management on a familiar road: Failing to detect changes in variable speed limits. *Transp. Res. Part F Traffic Psychol. Behav.* **2016**, *38*, 37–46. [CrossRef]
5. Lee, C.; Abdel-Aty, M. Testing effects of warning messages and variable speed limits on driver behavior using driving simulator. *Transp. Res. Rec.* **2008**, *2069*, 55–64. [CrossRef]
6. Hellinga, B.; Mandelzys, M. Impact of driver compliance on the safety and operational impacts of freeway variable speed limit systems. *J. Transp. Eng.* **2011**, *137*, 260–268. [CrossRef]
7. Lehtonen, E.; Malhotra, N.; Starkey, N.J.; Charlton, S.G. Speedometer monitoring when driving with a speed warning system. *Eur. Transp. Res. Rev.* **2020**, *12*, 16. [CrossRef]
8. Jamson, S. Would those who need ISA, use it? Investigating the relationship between drivers' speed choice and their use of a voluntary ISA system. *Transp. Res. Part F Traffic Psychol. Behav.* **2006**, *9*, 195–206. [CrossRef]
9. Lai, F.; Carsten, O. What benefit does Intelligent Speed Adaptation deliver: A close examination of its effect on vehicle speeds. *Accid. Anal. Prev.* **2012**, *48*, 4–9. [CrossRef] [PubMed]
10. Whitmire, J., II; Morgan, J.F.; Oron-Gilad, T.; Hancock, P.A. The effect of in-vehicle warning systems on speed compliance in work zones. *Transp. Res. Part F Traffic Psychol. Behav.* **2011**, *14*, 331–340. [CrossRef]
11. Endsley, M.R. Toward a theory of situation awareness in dynamic systems. *Hum. Factors J. Hum. Factors Ergon. Soc.* **1995**, *37*, 32–64. [CrossRef]
12. Highways Agency. Highways Agency Policy for the Use of Variable Signs and Signals (VSS) Devices. *Interim Advice Note 162/12*. 2012. Available online: http://www.standardsforhighways.co.uk/ha/standards/ghost/ians/pdfs/ian162.pdf (accessed on 7 July 2022).
13. Highways England. *Traffic Signs Manual Chapter 1 Introduction*; 2018; Crown: London, UK; ISBN 9780115536014. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/771873/traffic-signs-manual-chapter-1.pdf (accessed on 7 July 2022).
14. *ISO/TS 16951:2004*; Road Vehicles—Ergonomic Aspects of Transport Information and Control Systems (TICS)—Procedures for Determining Priority of on-board Messages Presented to Drivers. International Organization for Standardization: Geneva, Switzerland, 2004.
15. Jerome, C.; Monk, C.; Campbell, J. Driver Vehicle Interface Design Assistance for Vehicle-to-Vehicle Technology Applications. In Proceedings of the 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Gothenburg, Sweden, 8–11 June 2015. No. 15–0452.
16. Brooke, J. Sus: A 'quick and dirty' usability scale. *Usability Eval. Ind.* **1996**, *189*, 4–7.
17. Van der Laan, J.D.; Heino, A.; De Waard, D. A simple procedure for the assessment of acceptance of advanced transport telematics. *Transp. Res. Part C Emerg. Technol.* **1997**, *5*, 1–10. [CrossRef]

18. Bangor, A.; Kortum, P.; Miller, J. Determining what individual SUS scores mean: Adding an adjective rating scale. *J. Usability Stud.* **2009**, *4*, 114–123.
19. Speiran, J.; Shakshuki, E. Emergency Electronic Brake Lights for the Smartphone VANET. *Procedia Comput. Sci.* **2022**, *203*, 51–60. [CrossRef]
20. Starkey, N.J.; Charlton, S.G.; Malhotra, N.; Lehtonen, E. Drivers' response to speed warnings provided by a smart phone app. *Transp. Res. Part C Emerg. Technol.* **2020**, *110*, 209–221. [CrossRef]
21. Ali, Y.; Sharma, A.; Haque, M.M.; Zheng, Z.; Saifuzzaman, M. The impact of the connected environment on driving behavior and safety: A driving simulator study. *Accid. Anal. Prev.* **2020**, *144*, 105643. [CrossRef] [PubMed]
22. Warner, H.W.; Åberg, L. The long-term effects of an ISA speed-warning device on drivers' speeding behaviour. *Transp. Res. Part F Traffic Psychol. Behav.* **2008**, *11*, 96–107. [CrossRef]
23. Orne, M.T. Demand characteristics and the concept of quasi-controls. In *Artifacts in Behavioral Research: Robert Rosenthal and Ralph L. Rosnow's Classic Books*; Oxford University Press: Oxford, UK, 2009; Volume 110, pp. 110–137.
24. Silvano, A.P. Impacts of Speed Limits and Information Systems on Speed Choice from a Safety Perspective. Doctoral dissertation, KTH Royal Institute of Technology, Stockholm, Sweden, 2013.