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Could Intelligent Speed Adaptation make overtaking unsafe?

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Abstract

This driving simulator study investigated how mandatory and voluntary ISA might affect a driver's overtaking decisions on rural roads, by presenting drivers with a variety of overtaking scenarios designed to evaluate both the frequency and safety of the manoeuvres. In half the overtaking scenarios, ISA was active and in the remainder ISA was switched off. A rural road was modelled with a number of 2+1 road sections, thus allowing drivers a protected overtaking opportunity. The results indicate that drivers became less inclined to initiate an overtaking manoeuvre when the mandatory ISA was active and this was particularly so when the overtaking opportunity was short. In addition to this, when ISA was activated drivers were more likely to have to abandon an overtaking, presumably due to running out of road. They also spent more time in the critical hatched area – a potentially unsafe behaviour. The quality of the overtaking manoeuvre was also affected when mandatory ISA was active, with drivers pulling out and cutting back in more sharply. In contrast, when driving with a voluntary ISA, overtaking behaviour remained mostly unchanged: drivers disengaged the function in approximately 70% of overtaking scenarios. The results of this study suggest that mandatory ISA could affect the safety of overtaking manoeuvres unless coupled with an adaptation period or other driver support functions that support safe overtaking.

Keywords: simulator; speed; Intelligent Speed Adaptation; overtaking

1 Introduction

An individual driver's choice of speed has been found to be relatively stable over time (Wasielewski, 1984; Haglund, 2000) but there are large differences between drivers. These differences can be due to the influence of relatively stable factors such as age (Parker, Manstead, Stradling, Reason and Baxter, 1992), gender (Shinar, Schechtman and Compton, 2001) and personality (Dahlen, 2005) or transient factors such as impairment (Philip, Sagaspe, Moore, Taillard and Charles, 2005) and distraction (Patten, Kircher, Östlund and Nilsson, 2004). Aspects of the road environment such as the perceived level of enforcement (Keall, Povey and Frith, 2001), road width (Pau and Angius, 2001) and roadside furniture (Elliott, McColl and Kennedy, 2003), also impact on speed choice. However, whilst these factors can influence speed choice, ultimately the driver retains control of its modulation.

This freedom of speed choice can mean that drivers misjudge or intentionally exceed the speed appropriate for a given situation and this can expose them to risk. For example, Mosedale and Purdy (2004) report that erroneous speed choice is a contributory factor in 18% of UK rural road accidents, with overtaking being one of the most risky manoeuvres. Clarke, Ward and Jones (1998) report that overtaking accidents accounted for almost 10% of fatal road accidents in their dataset and concluded that “the majority arose from a decision to start the overtake in unsuitable circumstances” (Clarke, Ward and Jones, 1999). The authors conclude that these errors are due to poor timing and speed choice, as opposed to poor vehicle handling skills.

Overtaking is a complex task, with the driver needing to monitor their interaction with a lead vehicle, estimate the time to collision of any oncoming vehicles and take into account the time required to complete the overtake based on their own speed and skill level. A task analysis undertaken by Hegeman, Brookhuis and Hoogendoorn, (2005), outlines five distinct phases of an overtaking manoeuvre, comprising almost twenty subtasks. With regards to speed, only some of these subtasks are of relevance to this paper, relating to a driver’s desired speed (i.e. if the car in front impeding this) and their willingness to exceed this desired speed if necessary (i.e. in order to overtake).

When overtaking, a driver will want to minimise the time they spend in the opposing lane and this may lead them to increase their speed, even if that requires them to exceed the speed limit on approach to the lead vehicle and as they pass it. However, when drivers are estimating the safety of a potential overtake, high speed reduces the amount of time available to make the decision and then execute the manoeuvre. Studies have shown that drivers, whilst being sensitive to variations in distance to an oncoming vehicle, are much more prone to inaccuracy in their estimates of the speed (Farber and Silver, 1967; Berggrund and Rumar, 1973; Quenault, Quinn and d'Eye, 1973). Farber et al. (1967) report that drivers could not discriminate between vehicles travelling at 50 or 100 km/h. This implies that drivers not only reject safe passing opportunities but also engage in unsafe overtaking where the speed of the oncoming vehicle is faster than estimated.

How might a system that limits the maximum speed of a vehicle impact on drivers’ overtaking behaviour? Given that mandatory Intelligent Speed Adaptation (ISA) has been shown to decrease the spread of a speed distribution by curtailing all speeds in excess of the limit (Carsten and Tate, 2005), we could hypothesise that this reduced speed variance would not only increase overall traffic safety (Garber and Gadiraju, 1989) but would also benefit individual safety by increasing the predictability of the speed of an oncoming vehicle in an overtaking scenario. This of course would only hold true if all vehicles were equipped with mandatory ISA, otherwise the situation may become even more unpredictable than at present. However past research has indicated that whilst drivers generally accept that ISA could improve traffic safety (Várhelyi and Mäkinen, 2001; Comte, 2000; Vlassenroot , 2007), they believe that overtaking situations could potentially become more risky (Comte, Wardman and Whelan, 2000), their reasoning being that spending longer in the overtaking manoeuvre increases their risk and that they would have to learn to adapt their driving style if they were using an ISA-equipped vehicle. This of course implies that drivers are admitting to travelling in excess of the speed limit whilst overtaking.

There have been numerous on-road and simulator studies that have investigated whether drivers behave differently when their vehicle is equipped with ISA, mostly reporting changes in speed choice, headway and lane keeping (Hjälmdahl and Várhelyi, 2004; Várhelyi and Mäkinen, 2001; Jamson, 2006). To date, no research has been carried out to evaluate if and how drivers' overtaking behaviour alters when using an ISA system.

If drivers commonly exceed the maximum speed limit in order to overtake, with ISA they may initially engage in erroneous overtaking manoeuvres (due to misjudging the time available), that require them to either abort part-way through or spend more time in the opposing lane, exposed to danger.

If drivers are unable to accurately forecast the amount of time required for a particular overtaking manoeuvre, an opt-out function would allow drivers to override the system in order to exceed the posted speed limit and complete their overtaking manoeuvre more quickly. Thus whilst exceeding the speed limit is obviously illegal, it may provide drivers with a mechanism for avoiding a head-on collision. This study therefore implemented both a mandatory and voluntary ISA system in order to compare the effects of each on overtaking propensity and safety.

The study reported here was designed to quantify how the presence of a mandatory (no opt-out function) or voluntary (with an opt-out function) ISA system might affect drivers' overtaking decisions on rural roads. The aim of the study was to evaluate whether the two systems had differing effects on driver behaviour in ways which could be safety-critical. The study was undertaken on a driving simulator allowing the presentation of a variety of overtaking scenarios in a safe and controlled environment. Behavioural measures related to overtaking were collected in order to evaluate both the propensity of drivers to overtake and the safety of those manoeuvres. In addition, subjective measures of acceptability were taken using the Van der Laan, Heino and De Waard (1997) scale, commonly used in evaluations of driver support systems (De Waard, Van der Hurst and Brookhuis, 1999; Comte, 2000). Acceptability scores tend to differ, depending on the type of ISA under investigation, but generally a mandatory ISA is less acceptable than a voluntary one. Mental workload was also assessed using the NASA TLX scale. Within the driving domain the NASA TLX has assessed workload in tests of orientation aid systems (Ashby, Fairclough and Parkes, 1991) and in an evaluation of ISA system (Comte, 2000). Previous research in the field has shown that drivers report changes in mental workload when driving with ISA. Increases in scores pertaining to “time pressure” and “frustration” have often been found (Comte, 2000; Várhelyi and Mäkinen, 2001).

2 Methodology

2.1 Driving simulator

The experiment was performed using the University of Leeds Driving Simulator, shown in Figure 1[1]. The simulator’s vehicle cab is based around a 2005 Jaguar S-type, with all of its driver controls fully operational. The vehicle’s internal Control Area Network (CAN) is used to transmit driver control information between the Jaguar and one of the networks of seven Linux-based PCs that manage the overall simulation. This ‘cab control’ PC receives data over Ethernet and transmits it to the ‘vehicle dynamics’ PC, which runs the vehicle model. The vehicle model returns data via cab control to command feedback so that the driver seated in the cab feels (steering torque and brake pedal), sees (dashboard instrumentation) and hears (80W 4.1 sound system provides audio cues of engine, transmission and environmental noise).

[1] http://www.its.leeds.ac.uk/facilities/uolds/

Figure 1: The Leeds Driving Simulator

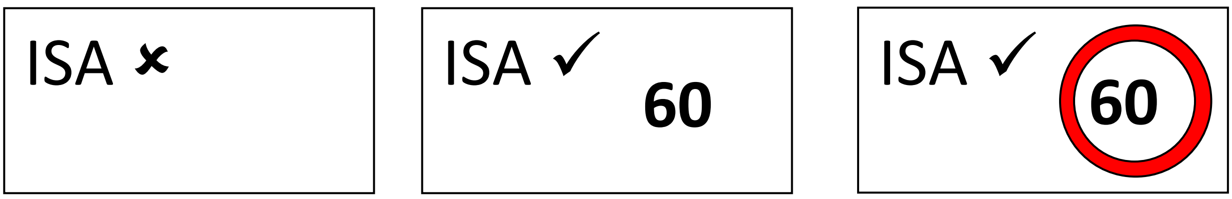
The Jaguar is housed within a 4m diameter, composite, spherical projection dome. A real-time, fully textured 3-D graphical scene of the virtual world is projected on the inner surface of the dome. This scene is generated by three further dedicated PCs on the local network, each housing an nVidia FX4500G graphics card. Each PC is used to render two of the six visual channels at 60 frames per second and at a resolution of 1024x768. The PCs are frame-locked to avoid any “tearing” of the visual image.

The projection system that displays the visual information consists of five forward channel and one rear channel. The forward channels are edge-blended to provide a near seamless total horizontal field of view of 250°. The vertical field of view is 45°. The rear channel (40°) is viewed only through the vehicle's rear view mirror. The display resolution of all channels is 4.1 arcmin per pixel.

The simulator incorporates an eight degree of freedom motion system. High and medium frequency lateral accelerations (e.g. a lane change) are simulated by sliding the whole vehicle cab and dome configuration along a railed gantry. Low frequency, sustained cues (e.g. a long, sweeping curve) are simulated using the tilt co-ordination of a 2.5t payload, electrically-driven hexapod. The whole gantry can also slide longitudinally along tracks to mimic the vehicle’s acceleration and braking. The 10m long rails and tracks allow 5m of effective travel in each direction. The motion-base enhances the fidelity of the simulator by proving realistic inertial forces to the driver during braking and cornering. It also provides lifelike high frequency heave, allowing the simulation of road roughness and bumps.

2.2 System functionality

Two types of ISA were modelled. The first, a voluntary system, could be activated by the driver by pressing a button on the steering wheel at which point the speed limit could not be exceeded. The voluntary ISA system could also be switched off using another button, also located on the steering wheel (no kick-down facility provided). Once this override button was pressed, the driver could travel at their desired speed. If however, their speed dropped below the speed limit, the system automatically re-engaged itself and they were limited to the speed limit again. The second, a mandatory system was permanently activated and could not be disengaged by the driver. Thus, in the mandatory trial, where ISA was available, drivers could not disengage it; however in the voluntary trial drivers could disengage ISA, where available. Participants were not given any instructions or advice as to whether to disengage the voluntary ISA. A simple interface was provided on the dashboard to inform drivers of the system status, Figure 2.



ISA is unavailable

ISA is available but the driver has opted out

ISA is available - the car is currently limited to 60 mph

Figure 2: ISA interface

2.3 Experimental design

Drivers took part in two separate trials in order to experience both mandatory and voluntary ISA. The trial with the mandatory system preceded the trial with the voluntary system, separated by approximately two months to reduce the carry-over effect. In each trial, drivers completed two drives each containing six overtaking scenarios. They thus encountered twelve overtaking scenarios in each trial, with ISA available in six of these. The analysis focussed on the effect of System Type (mandatory/voluntary), ISA State (on/off) and Overtaking Scenario (where 2+1 sections were 150, 200, or 350m) on the various measures of overtaking behaviour described in section 2.6.

2.4 Overtaking scenarios

Limitations in projection within the simulation can mean that the speed and distance of approaching vehicles in the opposing lane are difficult to perceive. From past experience we were aware that drivers can be reticent to overtake due to these limitations. We therefore created a scenario that allowed drivers to perform overtaking manoeuvres using a 2+1 road section; these overtaking lanes are used on rural (90 km/h) highways to allow drivers to pass safely. However, they still require drivers to make safety-related decisions as the additional lane eventually tapers out, potentially leaving the driver in a high risk situation if their judgement is poor. In this study, the end of the 2+1 sections was marked by hatching which tapered the two lanes down to one, Figure 3. Although this provided drivers with a protected overtaking opportunity, they were still obliged to perform manoeuvres safely (because of the hatching and the oncoming traffic in the opposing lane), taking into account the speed of the lead traffic, their maximum achievable speed and the length of the 2+1 section. In this respect, the 2+1 road section simply represents one of the many complex scenarios that drivers encounter, rather than replicating any one particular scenario.

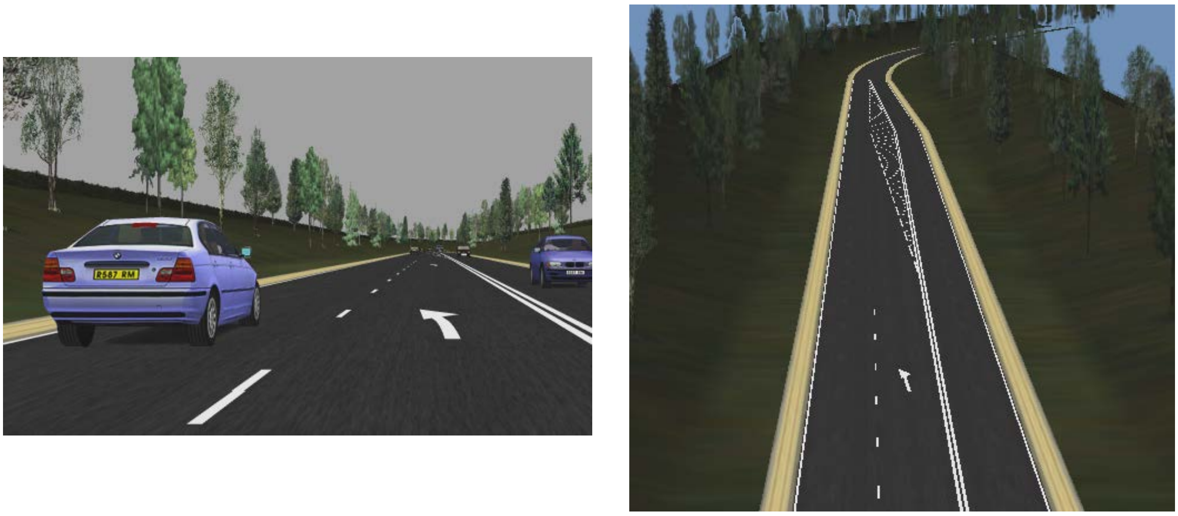


Figure 3: Road scene showing the overtaking lane

The length of the 2+1 section was varied, based on extensive piloting. We wished to create scenarios that required drivers to make safety decisions, but that did not create floor or ceiling effects in the data (i.e. none or all drivers overtook). The range of overtaking sections can be seen in Table 1. This design allowed us to vary task difficulty, ensuring that all drivers would have the opportunity to overtake — from those who actively search for overtaking opportunities to those who only do so when they believe the associated risk to be zero (no oncoming traffic and clear sight distance). The length of the two-lane section was the only attribute that was varied in the overtaking scenarios.

Table 1: Overtaking scenarios

Section	Road Section	ISA availability in Drive 1	ISA availability in Drive 2
1	2+1 (200m)	on	off
2	2+1 (350m)	on	off
3	2+1 (150m)	on	off
4	2+1 (200m)	off	on
5	2+1 (350m)	off	on
6	2+1 (150m)	off	on

The lead car was travelling at 70 km/h and oncoming cars at 90 km/h –although their presence did not impact on driver's behaviour in the "protected" 2+1 lane.

The overtaking scenarios were presented in the same order for each driver and were separated by filler sections of various lengths and curvature. All road sections were modelled according to current UK legislation (Design Manual for Roads and Bridges, 2005) and contained the appropriate signage for indicating the lane increase and decrease.

2.5 Participants

Twenty-six drivers completed both trials, recruited from an existing database. Of the twelve males who took part, five were 25-39 years old and seven were 40-60 years. Nine females were aged 25-39 years and five 40-60 years. All drivers were in possession of a full driving licence and had been driving for at least three years.

2.6 Behavioural measures

There were two main types of data of interest: the propensity of overtaking behaviour and the safety of any such behaviour. The following measures were recorded in each of the overtaking scenarios:

i. Overtaking outcome. A count was made of:
   a. The number of overtaking attempts made (no. of times the centre of gravity of the car crossed the centre-line).
   b. The number of successful overtakings (no. of cars passed, with no excursion into hatched area).
   c. The number of encroachments made (no. of excursions into hatched area).
   d. The number of abandoned overtakings (no. of times they moved out of lane but abandoned the overtaking by moving back before passing the lead car).
   e. The number of scenarios where no overtaking attempt was made.

ii. Overtaking safety. Calculations were made of:
   a. Minimum distance and time to collision to the rear of the lead vehicle during the overtaking manoeuvre. This provided a measure of how sharply drivers pulled out from behind the lead vehicle.
   b. Minimum distance to the front of the lead vehicle during the overtaking manoeuvre. This provided a measure of how sharply a driver pulled back in front of the lead vehicle.
   c. Time spent completing the overtaking manoeuvre.
   d. Maximum speed reached during the overtaking manoeuvre.
   e. Excursion into hatched area and the time spent in the hatched area.

An overtaking manoeuvre was deemed to have commenced when all four wheels had left the lane an ended when all four returned again.

2.7 Subjective measures

Drivers' acceptability of the ISA systems was measured using a scale developed by Van der Laan, Heino and De Waard (1997). Administration of the questionnaire allowed the calculation of an end score for each driver on the two dimensions of "usefulness" (e.g., useful-useless, scored +2 to -2) and "satisfaction" (e.g., pleasant-unpleasant, scored +2 to -2). The NASA TLX (Byers, Bittner and Hill, 1989) provided a measure of subjective workload. This tool involved formalising the driver's own judgement about the workload s/he experienced based on the assumption that workload is influenced by mental demand, physical demand, temporal demand, performance, frustration level and effort. Drivers placed a line on a bipolar scale (low-high) indicating their experience of each attribute.

2.8 Analytical approach

Due to the non-parametric nature of some of the data (frequencies), log-linear analysis was used in order to examine the impact of several categorical variables together as well as the interactions of each variable. Chi Square is insufficient when there are more than two qualitative variables because it only tests the independence of the variables. When there are more than two variables, it cannot detect the varying associations and interactions between the variables. Log-linear Analysis is a multivariate extension of Chi Square and is used when there are more than two qualitative variables; it is essentially a goodness-of-fit test that allows tests of all the effects (the main effects, the association effects and the interaction effects) at the same time. The algorithm used generates expected cell frequencies for each model and its respective goodness-of-fit statistic. In this case, the statistic is the likelihood ratio statistic and the goal is to find the model that best represents the data. Elsewhere, parametric testing was possible and repeated measures ANOVA was used for the analysis of workload and acceptability.

3 Results

3.1 Workload and acceptability

The workload scores for this experiment are shown in Figure 4. A repeated measures ANOVA indicated a significant main effect for System Type on the dimension of "performance" ($F(1,25) = 4.25$, $p < .05$), such that drivers rated their performance significantly better when driving with the voluntary system compared to the mandatory system. A main effect for System Type was also noted for the "frustration" dimension ($F(1,25) = 7.11$, $p < .05$) such that, compared to a voluntary system, drivers experienced more frustration when driving with a mandatory system. No other main effects were found.

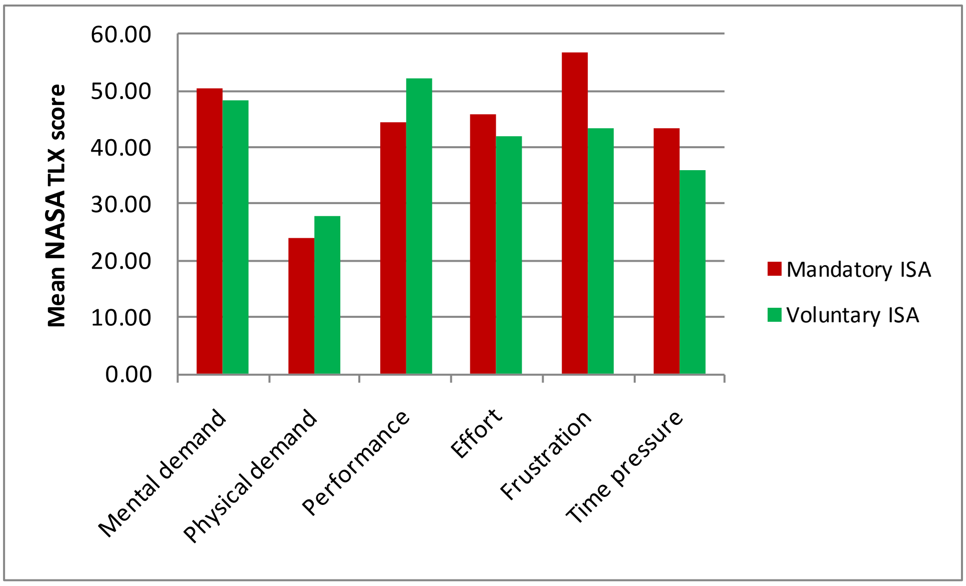


Figure 4: Mental workload scores

The acceptability scores shown in Figure 5 demonstrated that drivers rated the ISA systems more highly in terms of Usefulness than Satisfaction. A repeated measures ANOVA indicated that there was a significant main effect of System Type on the dimension of usefulness ($F(1,25) = 4.50$, $p < .05$) such that drivers perceived the mandatory system as significantly more useful than the voluntary system. Scores relating to the dimension of Satisfaction showed no significant difference across the systems.

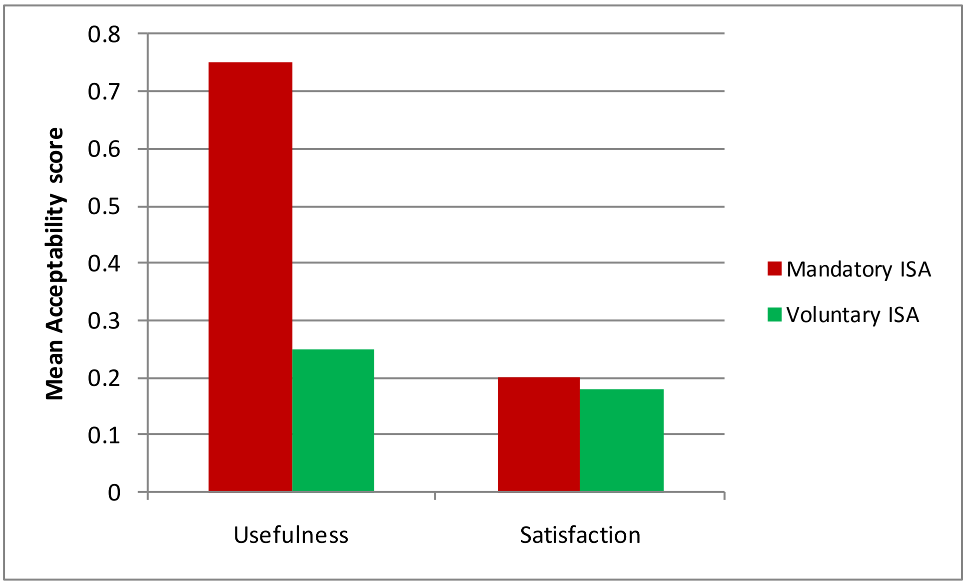


Figure 5: Acceptability scores

3.2 Overtaking attempts

Each driver encountered a total of six overtaking scenarios with each ISA system. The number of overtaking manoeuvres attempted in each of the overtaking scenarios is shown in Table 2. The number of overtaking attempts can vary greatly, as drivers could attempt several times in one overtaking scenario. Drivers showed a greater propensity to attempt to overtake when driving with the voluntary ISA system available (114 attempts) compared to the mandatory one (78 attempts). For voluntary ISA, the number of overtaking attempts did not differ between the ISA off and ISA on situations, suggesting that drivers opted out of the voluntary system when faced with an overtaking decision. In fact, drivers opted out, on average in 70% of the overtaking scenarios, spending approximately 20% of the total trial time opted out. In contrast, when the mandatory ISA system was engaged the number of attempted manoeuvres almost halved in some scenarios.

Table 2: Number of overtaking attempts

	Mandatory ISA		Voluntary ISA		
	ISA Off	ISA On	ISA Off	ISA On	No. of overrides
2+1 (150m)	39	26	37	34	36
2+1 (200m)	40	26	40	40	39
2+1 (350m)	41	26	40	40	36
Total	120	78	117	114	111

In order to examine the relationship between these variables, a four-way log-linear analysis was used to discover if the number of overtaking attempts was affected by System Type, ISA State or Overtaking Scenario (System Type x ISA State x Overtaking Scenario x Attempt). The four-way log-linear analysis produced a final model that retained the System Type x ISA State x Attempt interaction. The likelihood ratio of this model was χ^2 (16) = 3.11, $p = 1$. The System Type x ISA State x Attempt interaction was significant, χ^2 (1) = 9.56, $p < .01$. To break down this effect, separate chi-square tests on the ISA State and Attempt variables were performed separately for each system. For the mandatory ISA system there was a significant association between whether or not the system was activated and the number of attempted overtakes, χ^2 (1) = 24.38, $p < .001$**.** Drivers were less likely to attempt an overtaking manoeuvre if the mandatory system was active than if the mandatory system was not active (odds ratio 3.33). When ISA was active there was a 35% reduction in the number of overtaking attempts made. There was no significant association between whether or not the voluntary system was active and the number of attempted overtaking manoeuvres. It should also be noted that the propensity to overtake was very similar in both the ISA off conditions, suggesting that the ordering of the trials had little impact on the data.

3.3 Overtaking outcome

Drivers' overtaking behaviour was categorised as being successful or not. An overtaking was defined as successful if the driver did not enter the hatched area at the end of the overtaking lane. When driving with mandatory ISA the number of successful overtaking manoeuvres was lower when the system was engaged, Figure 6, a pattern not observed for voluntary ISA.

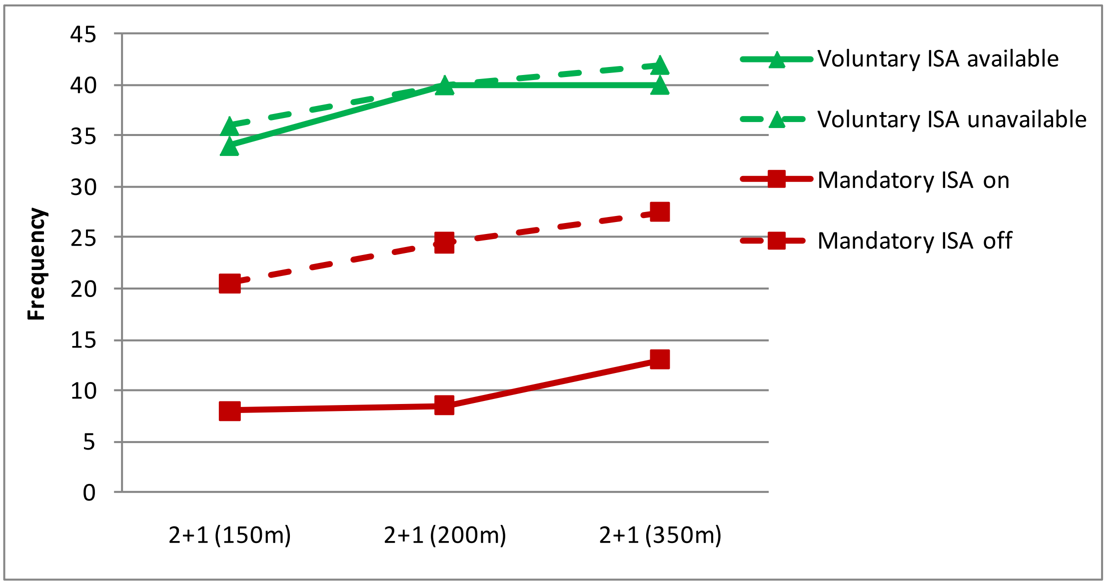


Figure 6: Frequency of successful overtaking

A four-way log-linear analysis produced a final model that retained the System Type x ISA State x Success interaction. The likelihood ratio of this model was χ^2 (16) = 8.02, p = .948. The System Type x ISA State x Success interaction was significant χ^2 (1) = 23.05, p < .001). To break down this effect, separate chi-square tests on the ISA State and Success variables were performed separately for each system. For mandatory ISA, there was a significant association between whether or not the system was activated and the number of successful overtakes, χ^2 (1) = 55.85, p < .001. Drivers were less likely to make a successful overtaking manoeuvre if the mandatory ISA was active than if it was not active (odds ratio 6.10). When ISA was active there was a 59% reduction in the number of successful overtaking attempts made. In contrast, there was no significant association between whether or not the voluntary system was active and the number of successful overtaking manoeuvres.

With regards to those overtaking manoeuvres that were abandoned part-way through, there were relatively few instances of these safety critical manoeuvres and those that did occur tended to happen when mandatory ISA was active, Figure 7.

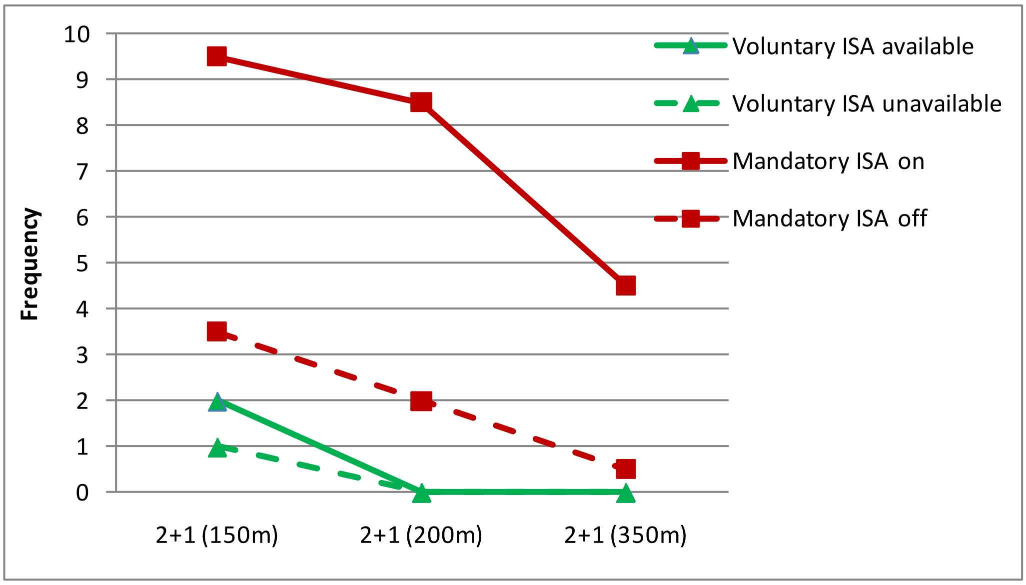


Figure 7: Frequency of abandoned overtaking

Scant data prohibited statistical testing of the relationship between the key variables and the number of abandoned overtaking manoeuvres.

3.4 Overtaking safety

Safety during overtaking is usually measured using indices of time-to-collision to oncoming traffic. As this experiment used overtaking lanes, the measure of safety used the hatching at the end of the overtaking lane as the "critical object". If drivers encroached onto this hatching, this was considered to be poor planning and in real-life could be safety-critical if oncoming traffic was present.

Figure 8 shows that drivers were marginally less likely to encroach into the hatched area when driving with voluntary ISA.

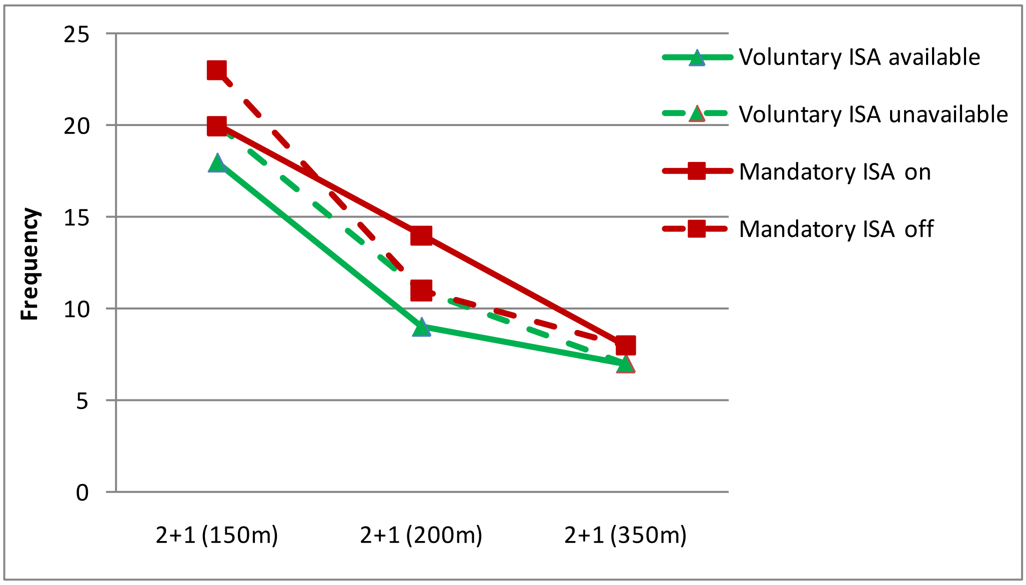


Figure 8: Frequency of encroachments

When examining this by overtaking scenario, the frequency of encroachments is relatively comparable across systems and ISA states (although encroachments were more frequent in the shorter 2+1 sections). A four-way log-linear analysis produced a final model that retained the Overtaking Scenario x Encroachment interaction. The likelihood ratio of this model was χ^2 (18) = 1.05, p = 1. The Overtaking Scenario x Encroachment interaction was significant χ^2 (2) = 32.43, $p < .001$. This interaction indicates that the ratio of encroachments to non-encroachments was different across the overtaking scenarios. In general the likelihood of encroaching into the hatched area increased in line with a decrease in the taper available in the overtaking scenarios. The ratio of encroachments to non-encroachments was roughly 40:60 for the 150m scenario, 20:80 for the 200m scenario and 10:90 for the 350m scenario.

As a measure of severity, the amount of time spent in the hatched area was recorded, Figure 9. In general, when mandatory ISA was active, encroachments were more severe, with drivers spending an additional one second in the hatched area. Due to the limited number of occurrences statistical tests could not be performed.

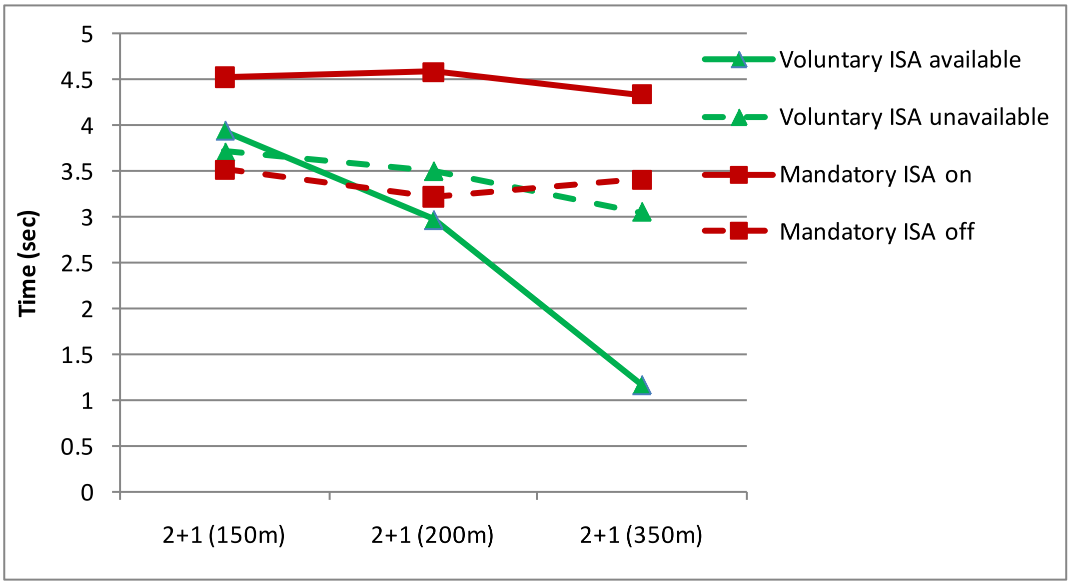


Figure 9: Severity of encroachment into hatched area

An additional measure of safety was gleaned from the separation distances between the driver and the lead vehicle whilst overtaking. As the driver instigated an overtaking manoeuvre, the minimum distance between the front of their vehicle and the rear of the lead vehicle was recorded. The minimum distance between the rear of the driver's car and the front of the lead vehicle was also recorded as the overtaking was concluded. These two measures of distance provide an indication of "cutting-in" and can be considered to be a measure of aggressiveness or lack of planning.

Repeated measures ANOVA revealed there to be no significant main effects of System Type or Overtaking Scenario on either the mean minimum distance to the rear of the lead vehicle when pulling out to overtake or when pulling back in (and no significant interactions). However, an interaction between System Type and ISA state was present, whereby drivers positioned themselves closer to the lead car when pulling out ($F(1,11) = 20.44$, $p < .001$) and pulling back in ($F(1,11) = 19.58$, $p < .001$), when using mandatory ISA, see Figure 10 and Figure 11.

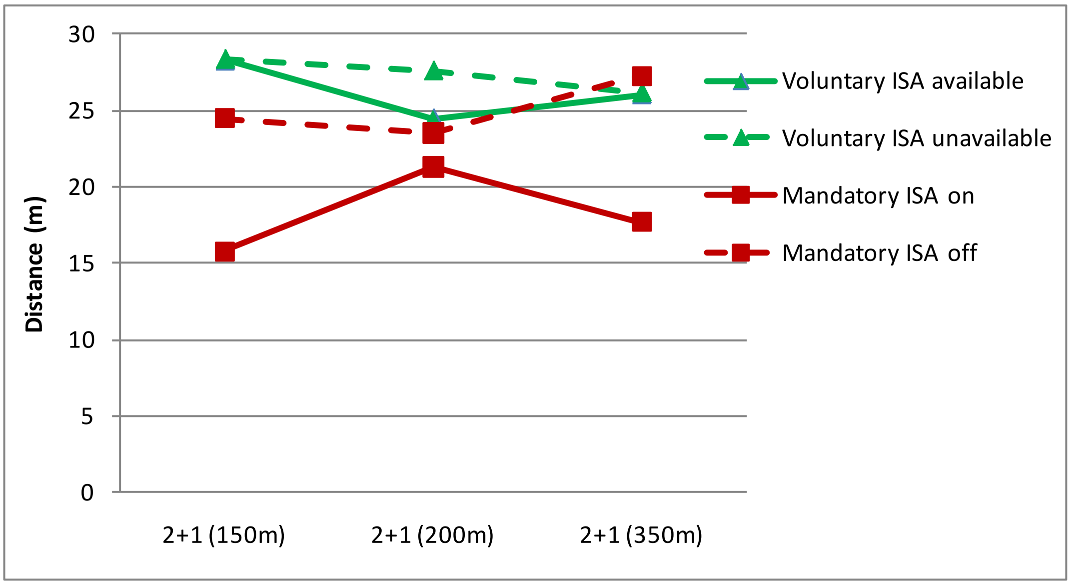


Figure 10: Minimum distance to the rear of the lead vehicle whilst overtaking

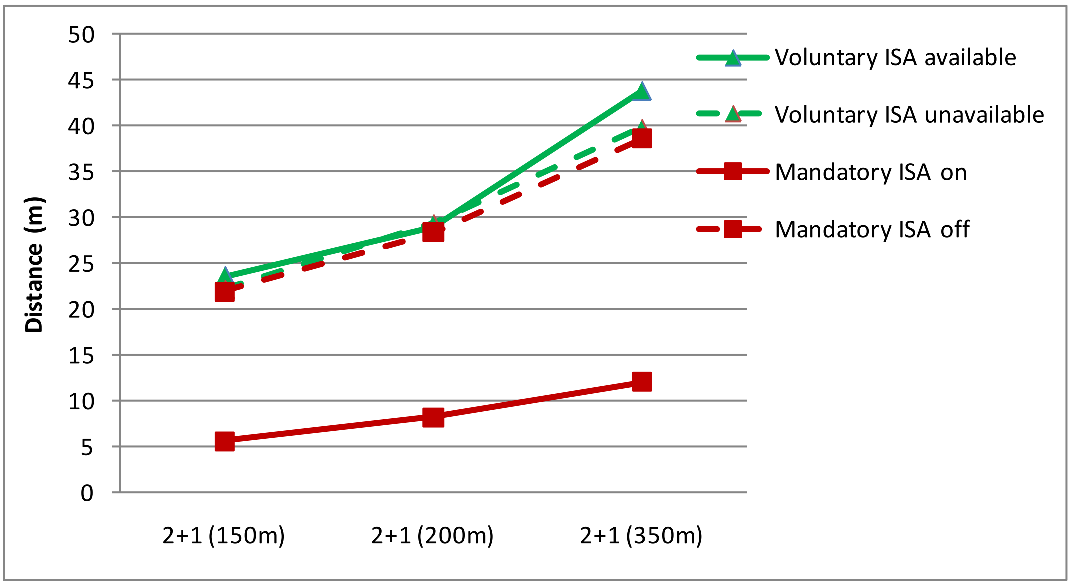


Figure 11: Minimum distance to the front of the lead vehicle whilst overtaking

Whilst overtaking, one would expect drivers to increase their speed, in order to minimise their time in the overtaking lane. Maximum speed in the overtaking lane was calculated – when driving with a voluntary system, drivers tended to adopt similar maximum speeds when overtaking whether the system was active or inactive. When driving with a mandatory system however, the difference was much more apparent. A repeated measures ANOVA confirmed a significant System Type by ISA State interaction ($F(1,11) = 262.01$, $p < .001$) indicating that when mandatory ISA was active, drivers travelled significantly slower than when ISA was not enacted. The difference was in the region of 20 km/h and meant that drivers were taking on average 20% longer to complete the overtaking manoeuvre.

4 Discussion and conclusions

This simulator study allowed us to investigate whether drivers' overtaking behaviour changed when a mandatory or voluntary ISA system was active. Almost all the drivers who took part in the experiment chose to overtake in at least some of the scenarios, despite not being primed to do so. This was, in part, due to the way in which the traffic was choreographed, with the lead car travelling significantly slower than the posted speed limit. However, this study was not intended to evaluate the propensity to overtake per se, but rather how propensity changed with and without ISA. The results are limited to the 2+1 scenario under investigation, but the judgements that drivers had to make in this study could equally apply to normal overtaking scenarios.

Questionnaire measures mirrored those found in many previous studies (e.g., Comte and Carsten, 1999) suggesting that whilst drivers deemed mandatory ISA more useful than a voluntary one, they also found it more frustrating to drive with and believed it impaired their driving performance. This indicates that drivers can see the logic behind ISA systems, in terms of its road safety benefits. However, when actually using ISA, they find the experience not as satisfying (although in this case the ratings are not negative).

The overtaking scenarios were chosen to allow drivers to engage in overtaking where they were not under too much time pressure (with a 350m taper) and where the manoeuvre was more safety critical (150m taper). The length of the taper had differing effects on driver behaviour; in the shorter taper we observed more encroachments and potentially safety-critical behaviour.

Overall the behavioural results indicated that drivers become less inclined to undertake overtaking when mandatory ISA was active and when they did the outcome was less likely to be successful and more likely to lead to an abandonment of the overtaking. In addition, the safety of the overtaking was compromised in terms of their interaction with the lead vehicle by leaving a smaller safety margin as they pulled out and then back in again. Reassuringly, drivers were not inclined to carry on with an ill-timed overtaking and chose to drop back behind the lead car – they did not encroach on the hatched area more frequently than when ISA was inactive. More interestingly however, when the *amount* of time spent in the hatched area was considered, those with mandatory ISA active spent longer there. These effects were not apparent when considering the voluntary ISA system where there was no difference on the number of attempted and successful overtakes when ISA was inactive or active. Given this and the frequency with which drivers overrode the system, drivers seem to routinely disable the ISA system when making an overtaking manoeuvre.

With ISA inactive drivers overtook the lead car faster and thus were able to rejoin the lane more quickly. Whether this represents a safety benefit is questionable as higher speeds could increase the frequency of loss of control accidents. However not being able to rejoin the inside lane swiftly brings its own risks. Under any full implementation of ISA, drivers would need to learn the limitations of their vehicle in overtaking situations. Again such effects were not observed with the voluntary ISA system. The activation of voluntary ISA did not affect drivers 'cutting in' behaviour or maximum speed when overtaking. Results again suggest that drivers quickly learnt to disable the system when performing an overtaking manoeuvre.

Unlike other driving behaviours, e.g. curve negotiation (Godthelp, 1986) and braking (Yilmaz & Warren, 1995), an in-depth understanding of the processes involved in overtaking is lacking in the research literature. Studies that have been undertaken have tended to focus on drivers' estimations of speed and distance (Jones and Heimstra, 1964; Gordon and Mast, 1970). More recently, drivers have been found to use different strategies in their overtaking decisions; for example Gray and Regan, (2005) evaluated overtaking manoeuvres with no oncoming traffic in a driving simulator and reported large individual differences distilling to three basic strategies. Some drivers used a temporal margin to instigate overtaking, whilst others used distance and a third group used time-to-collision. The authors suggest that the reasons why drivers make errors is because they are poor at making estimations of absolute distance and that judgements that rely on temporal information may be reliant on learning processes (i.e. novice drivers are more prone to errors, Clarke et al. 1998).

Could these errors be exacerbated or mediated by implementing ISA? In the current study, the voluntary ISA system had little influence on drivers overtaking behaviour, with drivers preferring to disengage the system in the majority of overtaking scenarios. However, with mandatory ISA, whilst the propensity to overtake reduced, the quality of those manoeuvres undertaken was compromised. This is presumably due to errors in temporal and distance judgment, possibly worsened by the disturbance of their normal driving strategy (i.e. exceeding the speed limit whilst overtaking). Novice drivers may benefit from mandatory ISA if it prevents them from engaging in overtaking behaviours, however it is likely that overtaking is a skill that requires honing through training and real-life experience. In terms of implementation therefore, it may be considered that mandatory ISA should be combined with a system such as that proposed by Hegeman, Tapani and Hoogendoorn (2009). The system they propose would assist drivers in judging the safety of gaps in the oncoming traffic stream, by means of a simple interface. Such a support system could provide a valuable feedback mechanism for drivers regarding the safety of overtaking opportunities and if combined with a mandatory ISA could realise the traffic safety benefits reported elsewhere.

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