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Exploring the relationship between risk perception, speed limit credibility and speed limit compliance

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Abstract

Driving speed is an important factor in road safety. Speed limit compliance is not only affected by the speed limit credibility, but is also related to driver's risk perception. This study investigates the relationship between the factors of risk perception, speed limit credibility and speed limit compliance for a given rural single carriageway road and roadside environment. Speed limit credibility, subjective risk perception and compliance with the speed limit were measured separately. To be specific, speed limit credibility was measured by speed limit rating score using a picture questionnaire. Subjective risk perception was measured by risk rating in an automated car driving simulator for a given speed and road environment. Speed limit compliance was measured by percentage of driving time spent below the speed limit in a simulated manual driving task with a given speed limit and road environment. Multilevel regression and logistic regression analysis demonstrate that risk perception has a positive influence on compliance with the speed limit. Credibility of speed limit has a positive influence on speed limit compliance. Risk perception has a negative influence on speed limit credibility. The research results can be used for guiding speed limit design and speed management.

Keywords: Speed Limit; Credibility; Risk Perception; Compliance

1 Introduction

Speed is a contributing factor to a significant number of road accidents, and the consequences of accidents generally increase with increasing speed (Aarts and Van Schagen, 2006; Elvik et al., 2009). Speed management is a central part of a safe system, such that speed must be limited at a level commensurate with the inherent safety of the road system (Tingvall and Haworth, 2000). The aim of setting speed limits is to regulate the maximum speed at which vehicles operate on public roads, in keeping with the overall strategy for speed management (Elvik, 2012), especially targeting those who would violate speed rules and endanger others.

A credible speed limit is one that drivers consider logical or appropriate in light of the characteristics of the road and its immediate surroundings through specific consistency and continuity of road design, including the type of road, road layout, road surface, road curvature, traffic density, weather conditions and a mix of traffic. Each road scene should match a speed limit which is accepted by most drivers. In this research, speed limit credibility refers to the common agreement of drivers that one speed limit is appropriate and safe for one road scene, based on the subjects' comparable feelings and judgement of whether a driving speed is appropriate (neither too fast nor too slow) for a given road, and that the driving speed does not bring any unsafe feelings.

SWOV (2012a) describes a credible speed limit as a limit that matches the image evoked by the road and the traffic situation. Goldenbeld and van Schagen (2007) and SWOV (2012b) claim that certain specific road and environment combination features influence the credibility of the speed limit. The road environment refers to road design and road layout based on engineering. van Nes et al. (2007) list five road and road environment characteristics influencing the credibility of speed limits: road marking, parking facilities, pedestrian facilities, cyclist facilities and intersection type. Road layout features which influence credibility on 80km/h rural roads in the Netherlands include road width, road curve, road view and sight distance (Goldenbeld and van Schagen, 2007). Differences between the characteristics of the road environment, such as the presence or absence of curves, and sight distance and clarity, lead to different perceptions of preferred and safe speed limits.

Road and roadside environment affecting speed choice are determined by road geometry, road surfacing, weather conditions and traffic situations, etc. Higher speeds are chosen on roads which are wide, with emergency lanes, fewer bends, a smooth surface, clear road markings, fewer buildings and less vegetation (Elliott et al., 2003; Goldenbeld and van Schagen, 2007; SWOV, 2012a). Features such as edge markings that visually narrow the road, the close proximity of buildings, reduced carriageway widths, obstructions in the carriageway and pedestrian activity, all tend to reduce speed (Kennedy et al., 2005). This research focuses on the rural single carriageway. As hard shoulders, cycle lanes and curved roads are the basic elements of road geometry considered to affect road safety (Wegman and Slop, 1998; Rosey et al., 2008; Rosey et al., 2009; SafetyNet, 2009). These three factors were considered in the experimental design in a rural road environment.

The geometry of the road influenced drivers' risk perception. The frequent intersections and driveways, the presence of horizontal curves, and pedestrians and sidewalks were justified to increase car drivers' perception of crash risk (Tarko, 2009). Wide medians, wide paved roadways, and wide lateral clearance to obstructions were justified to reduce the perceived risk (Tarko, 2009; Montella et al., 2015). The vehicle stability and stopping sight distance also depend on the radius of curve. Drivers perceive high risk on curved roads although they drive at a low speed.

Achieving drivers' compliance with the speed limit is a crucial issue in effective speed management. Compliance refers to driving speed behaviour. A driver's choice of speed is affected by various factors of which speed limit credibility is an important one. If a driver's speed is less than or equal to the given speed limit, the driver is compliant with the speed limit. Credible speed limits are supposed to result in better driver compliance (SWOV, 2012b). A non-credible speed limit can cause uncertainty for drivers. Credible speed limits should be evidence-led and self-explaining and reinforce motorists' assessments of a safe speed to travel (Department for Transport, 2013). Self-explaining roads (SER) are roads on which the driver naturally adopts behaviour consistent with the design and function (Theeuwes, 1998). Road users choose their speed based not only on speed limit signs but on visual cues derived from the road scene (Ivan and Koren, 2014). Therefore, there is a need to verify that improving speed limit credibility increases compliance based on drivers' perceptions and behaviours.

Subjective risk perception comes from exposure to mixed traffic situations, the underlying probability of a crash and the probability of injury if a crash occurs (Peden et al., 2004). There are two definitions of risk perception in previous research. Slovic (1987) states that risk perception is a subjective assessment people make when they are asked to characterise and evaluate hazardous activities and technologies. Sjöberg *et al*. (2004) define risk perception as a "subjective assessment of the probability of a specified type of accident happening and how concerned we are with the consequences". Both the probability and the consequences of negative outcomes are considered. Because drivers have different perceptions of risk in a given situation, they may have different perceptions of the speed limit. Risk perception for individual road users is evaluated for the given road environment and the specific traffic situation. However, how drivers' risk perception affects speed limit credibility has not been tested in previous studies. Just as drivers can feel that a speed limit is too low (and therefore drive above the limit), they might in some situations feel that a speed limit is too high and impose too much risk. Hence, risk perception must be fully taken into consideration in linking with speed limit credibility.

Research has investigated the relationship between risk perception and driving speed. Wilde (1998) puts forward risk homeostasis theory (RHT) which claims that people adapt their driving behaviour to a lower or acceptable level of risk so that the number of accidents remains unchanged. Drivers compare the amount of perceived risk with their target risk and adjust their behaviour to eliminate discrepancies between them, which indicates that they select a non-zero level of risk with which they feel comfortable. The differences between drivers' speeds on the same road can be explained by individual differences in risk tolerance and perception of risk (Wilde, 1982). Summala's (1996) zero-risk theory claims that drivers do not behave in such a way as to maintain a preferred level of risk. Drivers' risk control is based on maintaining safety margins around themselves, operationalised as the distance the driver keeps from a hazard. For example, motorists avoid experiencing risky situations by controlling their driving speed and time-to-line crossing to ensure that they are not subject to risk (Summala, 1996). Risk allostasis theory claims that the feeling of risk, as an indication of task difficulty, is the primary controller of driver behaviour (Fuller and Santos, 2002; Fuller, 2005; Fuller et al., 2008). Drivers seek to maintain risk feeling within a preferred range by adapting their behaviour (Fuller, 2008b). Based on these studies, Wilde's risk homeostasis (Wilde, 1982), Summala's zero risk model (Summala, 1996) and Fuller's risk allostasis model (Fuller, 2008a) all apply to the task of driving. In summary, the above studies suggest that higher perceived risk is associated with a lower choice of speed. Risk perception affecting compliance with speed limits needs to be investigated as well.

2 Research hypotheses

In order to investigate the relationship between risk perception, speed limit credibility and speed limit compliance for a given road layout and roadside environment, the research builds a conceptual model linking road environment, risk perception, speed limit credibility and compliance with the speed limit. Each factor needs to be supported by measurement. There is a knowledge gap concerning the relationship between the factors, so links need to be built between each pair of factors. The model needs to be built, as described in the following hypotheses.

For rural single carriageways, road and roadside environment factors are proved to affect speed limit credibility, subjective risk perception and compliance with speed limits. The causal relationship between risk perception and credibility is tested in this study. Consequently, in a given rural single carriageway environment, the hypotheses test whether there is a significant relationship between risk perception and credibility, risk perception and compliance, and credibility and compliance.

- Hypothesis 1: Higher risk perception has a positive influence on compliance with speed limits.
- Hypothesis 2: Credible speed limit has a positive influence on compliance with speed limit.
- Hypothesis 3: Greater feeling of risk at a given speed has an influence on feeling that speed limit is too high (less credible).

In order to build the relationship between risk perception, speed limit credibility and speed limit compliance, three tasks were undertaken step by step. Task 1 was a paper-based questionnaire. Speed limit credibility rating was measured. Task 2 was a risk feeling task, measured in an automated driving condition in the driving simulator. Task 3 was a manual driving task in the driving simulator. Percentage of time a driver spends compliant with the speed limit was measured.

3 Method

3.1 Participants

Because of the focus on drivers, the participants were required to have a valid driving licence, no matter what their driving experience was. The gender, age and driving experience were balanced while recruiting participants. The total participants were 17 males and 17 females, age ranging from 18 to 62 (Mean=31.71, SD=14.41), driving experience from 1 year to 45 years (Mean= 12.10, SD= 13.41). This research had ethical approval from the Research Ethics & Governance Committee of the University of Leeds.

3.2 Apparatus

Monitor

For the questionnaire task (Task 1), a widescreen monitor was used to present a series of road scenes (Figure 1(a)). In total, eight screenshots of road scenes were presented on a 15” monitor. Each picture was followed by the questions shown in Table 2. For each question, the participants placed a mark on a sliding scale which described their reaction to the picture. The participants had to answer the questions in a given time.

Driving simulator

The risk feeling in an automated driving condition task (Task 2) and manual driving task (Task 3) were conducted in a motion-base, high-fidelity driving simulator (University of Leeds Driving Simulator) (Figure 1 (b)). The simulator vehicle has an adapted vehicle cab of a 2005 Jaguar S-type model, housed in a 4m spherical projection dome with a 300° field of view projection system. The internal controls and dashboard instrumentation function as they would in a fully-operational vehicle. In automated driving mode, the driving simulator is controlled automatically with SAE Level 2 vehicle automation (hands off, feet off, conditional automation). The dynamic visual stimuli and motion stimuli consist of the road environment and automation speed. A simulated road environment is shown in Figure 2.

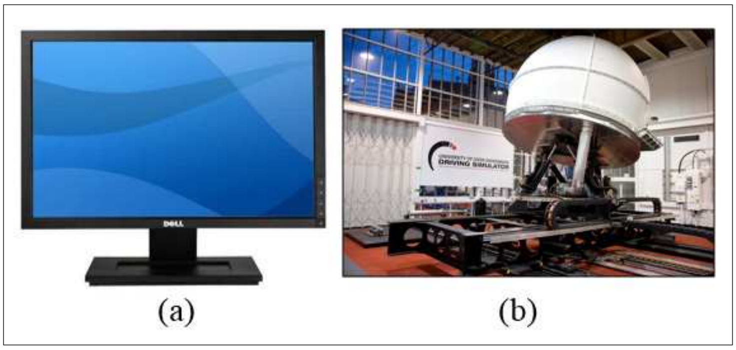

Figure 1 Experiment Apparatus

Figure 2 Simulated road environment example (Curve + Shoulder + Cycle lane)

3.3 Experimental design

The experimental design adopts 4-way within-subject factors, assuming each subject goes through all road scenarios (repeated measures). The eight road scenarios were modelled in the simulated scene to have a lane width of 3.65 m, curve radius of 200 m, hard shoulder width of 1m and a cycle lane width of 2 m. Each rural single carriageway layout is modelled according to the Design Manual for Roads and Bridges (Volumes 6 and 8), with road markings, widths and signage, all conforming to current UK legislation. Table 1 shows the experimental conditions.

Table 1 Experimental design

	Factors			
Experimental scenario number	**Road curve**	**Hard shoulder**	**Cycle lane**	**Rural Road scenes**
A	Present	Present	Present	Curve + Shoulder + Cycle lane
B	Present	Present	Absent	Curve + Shoulder

C	Present	Absent	Present	Curve + Cycle lane
D	Present	Absent	Absent	Curve only
E	Absent	Present	Present	Shoulder + Cycle lane
F	Absent	Present	Absent	Shoulder only
G	Absent	Absent	Present	Cycle lane only
H	Absent	Absent	Absent	Straight only

For Task 1, eight road pictures were presented to the participant drivers. A paper-based questionnaire was used. For Task 2, the automated driving task, for the 8 rural road layout combinations, three levels of speed (40 mph, 50 mph and 60 mph) were used, a 2×2×2×3 factorial design with a total of 24 automated driving scenarios. A counterbalanced design is more likely to identify true differences in the effects of the various conditions. Counterbalancing the order of treatment is a control for sequential confounding. The treatments follow one another in an unpredictable fashion to minimise carryover effects (Barlow and Hayes, 1979). For Task 3, manual driving in the driving simulator, three normal speed limit signs (40 mph, 50 mph and 60 mph) were presented on the 8 road layout, making a 2×2×2×3 factorial counterbalanced design for manual driving.
The experimental method model justifies the indicated path linkages in Figure 3. Credibility rating in Task 1 is a continuous variable from very non-credible (0) to very credible (100). Risk feeling rating in Task 2 is a continuous variable from very low risk (0) to very high risk (100). Compliance with speed limit level in Task 3 is the percentage of time a driver spends compliant with the speed limit which is a continuous variable from non-compliance (0) to compliance (1).

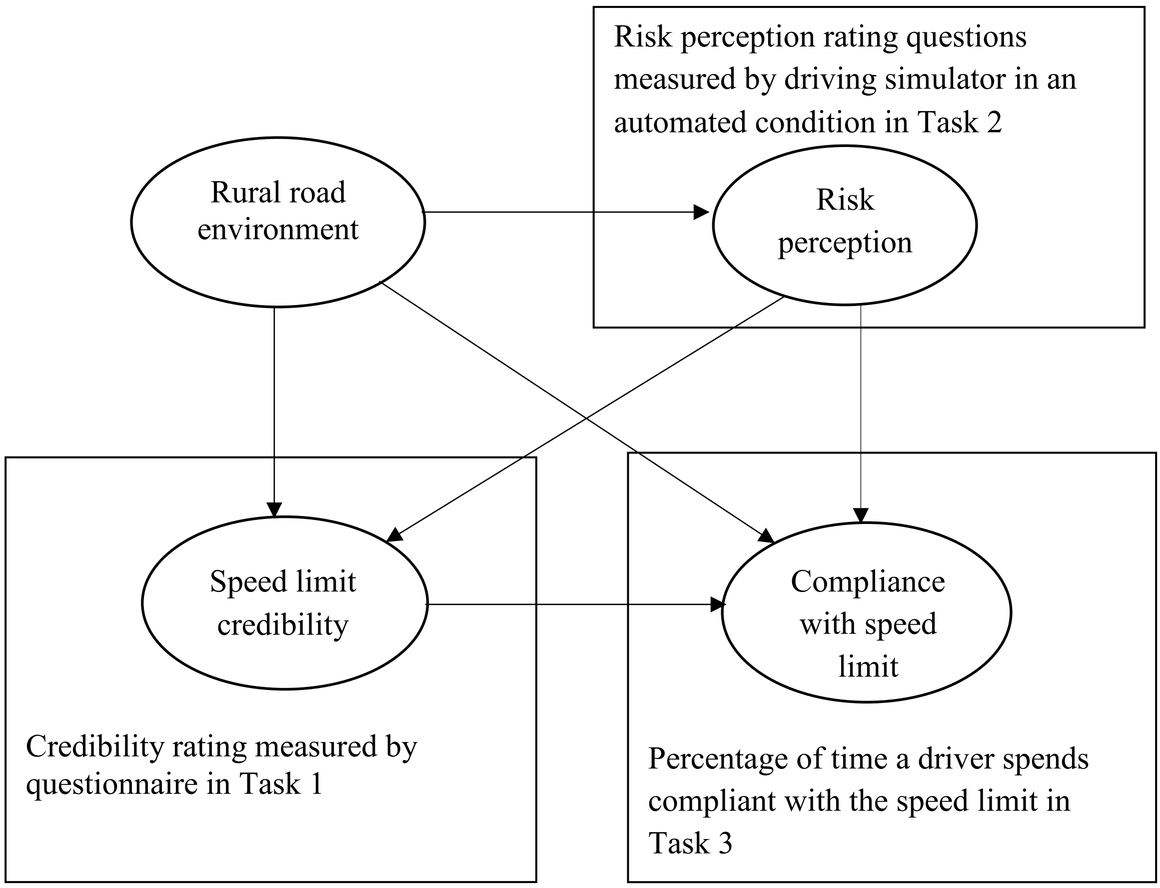

Figure 3 Experiment method model

3.4 Task procedure

After arriving at the simulator lab, the participants were briefed on the requirements of the study, ethical rights, risks and safety measures. Then the participants were given instructions for their role in the study, including general information on the questionnaire task, automated self-driving car and manual driving procedure. The subjects were required to sign consent forms and could withdraw at any time. They were asked to drive the simulator for at least 5 minutes to familiarise themselves with the controls of the car.

For Task 1, the participants remained seated in the office room facing a 15" monitor and filled in a paper-based questionnaire. The experimenter presented the rural road picture slides, to ensure the questions and pictures were time matched. The participant was told that a series of pictures would be presented and speed limit credibility rating question asked for each picture on the paper-based questionnaire.

For Task 2, the driving simulator in an automated condition was precisely controlled in terms of timing. The trial started with a 120s baseline (calm down and relax time). The experiment presented the road scenes at inter-stimulus intervals of 75s. For each road scene presentation, the visual scene faded in with a constant automated driving speed for 15s, followed by a 30s risk rating questionnaire and a 30s recovery period. An opposite vehicle passed the own vehicle in the middle of each stimulus, followed by another stimulus until all 24 automated driving stimuli were done. During the questionnaire and recovery periods, no visual scene or motion was presented to the participants.

For Task 3, each subject was asked to drive through all road scenarios, which followed in a balanced sequence. They were told to drive as they usually would along a rural road. It is assumed that the participants would select the driving speeds at which they felt comfortable and optimise their performance.

The three tasks took approximately 120 minutes to complete. Between each trial, the participants were allowed a short break. On completion of the three tasks, the participants were debriefed and paid £10.

3.4.1 Task 1 Speed limit credibility rating

For Task 1, the questions involved rating the speed limit perception of eight road pictures from very non-credible (0) to very credible (100). The higher the score, the more credibility the speed limit had. The respondents gave their answers on a visual analogue scale on paper (Table 2).

Table 2 Credibility rating questionnaire survey _ Task 1

How do you perceive a 60 mph speed limit on this type of road? Very non-credible--------------------------------------Very credible
How do you perceive a 50 mph speed limit on this type of road? Very non-credible--------------------------------------Very credible
How do you perceive a 40 mph speed limit on this type of road? Very non-credible--------------------------------------Very credible

3.4.2 Task 2 Risk rating

For Task 2, the participants were introduced to the driving simulator. There were 24 automated driving stimuli presented in total. The paper-based questionnaire asked the participants to rate risk feeling at a given speed (40 mph, 50 mph, and 60 mph) for eight different types of road. The risk perception was rated as a continuous value from very low risk (0) to very high risk (100). The respondents gave their answers on a visual analogue scale on paper (Table 3).

Table 3 Risk perception questionnaire survey _ Task 2

Automation condition in driving simulator	With regards to the risk outcome of the current driving speed on this road, how risk would you feel? Very low risk --------------------------------------Very high risk

3.4.3 Task 3 Compliance with speed limit

Task 3 was a manual driving task in which each participant was required to complete eight layout routes. Each route was presented with three speed limit signs (40 mph, 50 mph and 60 mph). The order of the routes and signs was balanced. The drivers drove at a mean speed below 60 mph on all the curved roads and a mean speed below 60 mph on all the straight roads. Thus, the mean speed was not high enough to reflect the real compliance level. The proportion of driving time spent below the speed limit gave better results for compliance with speed limit level, measured as a continuous variable from not compliance at all 0% to fully compliance 100%.

3.5 Statistical analysis

3.5.1 Multilevel regression

The classical regression method has a heterogeneity problem for data in a longitudinal format (Cohen and Cohen, 2010; Hox, 2010). The mixed-effect models (multilevel regression) are extensions of linear regression models for data that are collected and summarised in groups. The fixed effects model in matrix notation is shown in Equation 1:

$$Yij = \alpha i + \delta j + \beta xij + \varepsilon ij \qquad (1)$$

Where x_{ij} represents the explanatory variable of the ith driver in jth speed limit/road type. Equation 1 adds an intercept denoted by αi, where δj denotes a dummy variable for each speed limit/road type. It assumes that the regression coefficients are constant across drivers and speed limit/road types. However, Equation 1 makes no attempt to explicitly model the repeated observations. Fixed effects and random effects models do just this and address some of the problems associated with estimating the constant coefficients model via ordinary least squares (OLS). The driver is a random effect so that zero correlation exists between the error term and predictor variable. The random effects model is shown in Equation 2:

$$Yij = \alpha i + \beta xij + \upsilon i + \omega j + \varepsilon ij \qquad (2)$$

Treatment levels are usually fixed effects, while subjective effects are almost random effects. It is clear that, in each group, there is a random subject to subject variation in the intercept.

Equation 2 assumes that the unobserved differences between drivers are random variables, where υi and ωj denote separate error terms. They represent between-driver variation and are the disturbance terms associated with the analysis. For the fixed effect part, if a predictor does not vary over time, it is perfectly collinear with the unit dummies in a fixed effects setting. With the use of unit-specific dummy variables in a fixed effects context, we can control for unobserved differences between each speed limit.

3.5.2 Binary logistic regression

The binary logistic regression function is written as:

$$\text{logit(Y)} = \ln\left(\frac{\text{x}}{1-\text{x}}\right) = \alpha + \beta X \qquad (3)$$

According to Equation 3, the relationship between logit (Y) and X is linear. The value of the coefficient β determines the direction of the relationship between X and the logit of Y. When β is greater than zero, larger (or smaller) X values are associated with larger (or smaller) logits of Y. Conversely, if β is less than zero, larger (or smaller) X values are associated with smaller (or larger) logits of Y.

$$\text{x} = \text{Probability (Y = outcome of interest} \mid \text{X = x)} = \frac{\text{e}\hat{}(\alpha + \beta \text{X})}{1 + \text{e}\hat{}(\alpha + \beta \text{X})} \qquad (4)$$

In Equation 4, x is the probability of the outcome of interest or event, such as driver compliance with the speed limit or not, α is the Y-intercept, β is the regression coefficient, e=2.71828 is the base of the system of natural logarithms, X is a continuous explanatory variable, and Y is a categorical dependent variable.

4 Data analyses

4.1 Variables coding

Credibility rating is a continuous variable from very non-credible (0) to very credible (100). Risk feeling rating is a continuous variable from very low risk (0) to very high risk (100). Compliance with speed limit level is the percentage of time a driver spends compliant with the speed limit which is a continuous variable from non-compliance (0) to compliance (1). With an arbitrary threshold of 0.5, compliance with speed limit level can also be transformed into two levels, non-compliance (0) and compliance (1).

The repeated measures ANOVA was used for testing the omnibus null hypothesis. In terms of speed limit credibility rating, there was no significant difference among the four curved roads at a given speed limit of 40mph and at a given speed limit of 50mph. There was no significant difference among the four straight roads at a given speed limit of 50mph. In terms of risk rating on the four curved roads, there was no significant difference between the four curved roads at a given speed of 40mph and at a given speed of 50mph. In terms of risk rating on the four straight roads, there was no significant difference among the four straight roads at 50mph and there was no significant difference at 60mph.

Thus, presence/absence of shoulder and presence/absence of cycle lane did not affect either risk feeling on curved roads and on straight roads. In the following data analysis, rural road scenes (A, B, C, D) are grouped as curved roads and rural road scenes (E, F, G, H) are grouped as straight roads. For example, the road type explanatory variable is coded as 0 for the curved road and 1 for the straight road. In addition, the 40 mph speed limit explanatory variable is coded 0, the 50 mph speed limit 1, and the 60 mph speed limit 2. By using multilevel models, it can test whether variances differ between conditions or whether variance depends on continuous measures (Raudenbush and Bryk, 2002).

4.2 Investigating the relationship between risk perception and compliance with speed limit

Linear regression models (Model 1) are used to examine the linear relationship between risk perception and compliance with the speed limit. Compliance with the speed limit is a dependent variable and risk perception is considered as the explanatory variable. However, the simple linear model with an intercept and slope completely ignores the group nature of data. Model 2 fits a multilevel regression with a fixed effect for both speed limits and road types, and a random effect for the individual drivers. Since repeated measure is used, there is the possibility of unobserved heterogeneity across individuals. Generalised linear mixed models can account for this heterogeneity through random effects. The results are shown in Table 4.

Table 4 Multilevel models for the effect of risk perception on compliance with speed limit

	Model 1 Linear regression	**tStat**	**Model 2** (effect of road type and speed limit)	**tStat**
Fixed effect				
Intercept (se)	0.32*** (0.02)	15.25	0.34*** (0.04)	8.50
Risk (se)	0.01*** (0.001)	13.67	0.0022*** (0.00)	4.26
roadtype_straight (se)			-0.26*** (0.02)	-11.20
limit_50 (se)			0.30*** (0.02)	12.17
limit_60 (se)			0.48*** (0.03)	18.21
Random effects				
Driver 'intercept'			0.18	
Error 'Res Std'			0.28	
Degrees of freedom	814		811	
Adjusted R^2	0.19		0.58	
Cohens f^2			0.51	
Log Likelihood			-158.49	
AIC			330.97	

*** p<.01 ** p<.05 *p<.1

(se)-standard error; (CI)-confident interval

The comparative model results give each parameter, with its standard error (the difference between the predicted and observed value) in parentheses. Adjusted R^2 is the proportion of variance accounted for in regression. Cohen's measure of effect size in multiple regression is f^2, i.e., one variable's effect size within the context of a multivariate regression model (Cohen, 1988). Cohen defined values near 0.02 as small, near 0.15 as medium, and above 0.35 as large (Cohen, 1988). The Akaike information criterion (AIC) (Akaike, 1998) is a widely-used measure for comparing models with different error distributions, valid for both nested and non-nested models, and avoiding multiple testing interaction of risk and road type is clearly reasonable and needed in this model, as is the random intercept. Model 2 performs better than Model 1 because the predicted value can explain the variance of risk as a direct effect of compliance with speed limit controlled by road type and speed limit. In addition, for the adjusted R^2, the log likelihood value shows Model 2 to be statistically significant ($p<.001$).

Model 2, the mixed-effect model, fits the multilevel regression with a fixed effect for all speed limits (40 mph, 50 mph and 60 mph) and both road types (curved, straight), and a random effect for individual drivers. All the coefficient results are statistically significant. As limit_40 and roadtype_curve are the baselines, the fixed intercept value of 0.34 shows that the compliance level on a 40 mph speed limit curved road is 34%. The intercept for the straight road with 40 mph speed limit is 0.08, which is significantly lower than the curved road with 40 mph ($t=-11.202$, $p<.05$). For each presented 50 mph and 60 mph speed limit, the coefficient value should be added to the baseline 40 mph intercept. The risk coefficient of 0.0022 represents the average gain in compliance level for each increase in perception of risk for the baseline 40 mph on the curved road. The positive sign means that as the risk perception increases, drivers have a greater intention to comply with the speed limit in the manual driving. For the random effect, the effect of individual drivers represents the difference in intercept for each road type and speed limit. Here, the random effect can explain the percentage of explanatory standard deviation, which is 39.3%.

Drivers do perceive risk and respond in predictable ways, which supports H1: Higher risk perception has a positive influence on compliance with speed limits. The more risk feeling there is at a given speed, the more compliance there is with that speed limit. From Model 2, the coefficient results show that drivers have the highest compliance level on the curved road with a 60 mph speed limit, due to the speed limit being too high for the higher risk perception. In contrast, drivers have the lowest compliance level on the straight road with 40 mph speed limit. Most drivers exceed 40 mph because they feel very safe in a lower speed situation on straight roads. The model confirms that risk rating for a given speed and road environment affects compliance with the speed limit. In addition, compliance with the speed limit level is affected by whether the speed limit is credible or not, which is analysed in section 4.3.

4.3 Investigating the relationship between risk perception and speed limit credibility

The relationship between risk perception and speed limit credibility is explored using linear regression and a mixed effect model. Drivers' risk perception in a given road environment and speed is assumed to affect the perception of speed limit credibility. Model 3 builds a linear regression between risk perception and speed limit credibility. Model 4 involves both speed limit and road type as fixed and individual drivers as a random effect (Table 5).

Table 5 Multilevel models for the road effect of risk perception on speed limit credibility

	Model 3		**Model 4**	
	Linear regression	**tStat**	**effect of road type and speed limit**	**tStat**
Fixed effect				
Intercept	70.14***	46.85	65.72***	22.75

(se)	(1.50)		(2.888)	
Risk (se)	-0.31*** (0.04)	-8.39	-0.42*** (0.04)	-9.52
roadtype_straight (se)			-4.32** (1.99)	-2.17
limit_50 (se)			15.79*** (2.12)	7.46
limit_60 (se)			14.46*** (2.29)	6.30
Random effects				
Driver ‘intercept’			10.54	
Error ‘Res Std’			24.41	
Degrees of freedom	814		811	
Adjusted R^2	0.08		0.26	
Cohens f^2			0.07	
Log Likelihood			-3793.90	
AIC			7601.70	

*** p<.01 ** p<.05 *p<.1

According to the models tested, the overall effect of risk feeling is highly significant for credibility rating in a given road scenario. The more risk feeling in a high speed situation, the less credible the speed limit is. In Model 3, the linear regression cannot explain many of the explanatory variables, as the R^2 value is quite low. In Model 4, the fixed effect speed limit is significant for the relationship. The model explains that as the risk perception increases in a high speed situation, the credibility rating becomes even lower. A curved road with a 60 mph speed limit is perceived as more risk than other situations. Drivers perceive more risk on a curved road than a straight road, given the same speed limit. It is noteworthy that drivers perceive driving at 40 mph on a safe road places the own car and other vehicles in a very slow speed situation, which might lead to an unsafe feeling. Thus rated the speed limit less credible. A curved road with a 60 mph limit and a straight road with a 40 mph speed limit are seen as having the least credible speed limits compared to the other situations.

Adding road type and speed limit in Model 4 does not make any significant improvement. As the adjusted R^2 value for the mixed effect models (Model 4) is low. Therefore, it can be concluded that speed limit credibility level not only comes from risk perception but also from the road layout and roadside environment. Together, road layout and the roadside environment are the main contributors to speed limit credibility. In addition, the residual for each fitted fixed effect is quite large, which illustrates that individual perceptions of risk and perceptions of credibility are different from each other in a given road scenario. Both risk rating and credibility rating have larger variations because of the nature of subjective measurement, which has a bias.

4.4 Investigating the relationship between speed limit credibility and driver compliance with speed limit

The dataset only covers the credible speed limit on eight road types. Based on Task 1 and Task 2 results, speed limit credibility refers to the common agreement of drivers that one speed limit is appropriate (neither too fast nor too slow) and safe for one road scene. The credible speed limit was evaluated to be 40 mph on the curved road with 200 m radius, 50 mph on the straight road with a cycle lane, and 60 mph on the straight road without a cycle lane. The non-credible speed limits were excluded from the dataset.

In order to build the relationship between the independent variable speed limit credibility and the dependent variable compliance with credible speed limit level, the data pattern needs to be examined. Compliance with speed limit level from Task 3 was originally going to be explained by percentage of time compliant with the speed limit as a continuous variable from non-compliance (0) to compliance (1). However, most of the dependent variable percentages of driving time compliance with speed limit data fell at either 0 or 1, so the dependent variable can be transformed into a dichotomous outcome with a threshold of 0.5. If the percentage of time compliant with the speed limit is greater than 0.5, it is classified as 1, otherwise 0. Thus, the relationship between speed limit credibility and driver compliance is formulated as a binary logistic regression model. The independent variable stands for the credibility score (from 0 very non-credible to 100 very credible) and the dependent variable represents 1- compliance and 0- non-compliance.

Table 6 Logistic regression model estimating effects of credibility on compliance (N=272)

	Compliance with speed limit	Compliance with speed limit+10%	Compliance with speed limit+20%
Credibility score			
β credibility	.00	.01*	.02**
s.e.	.01	.01	.01
p value	.43	.08	.00
odds ratio	1.00	1.01	1.02
Constant			
α constant	-.68**	.42	.78*
s.e.	.34	.35	.41
p value	.04	.22	.06
Chi square	.64	2.99	8.57
Chi square p value	.43	.08	.00
-2 Log likelihood	363.97	315.41	196.39

*** p<.01 ** p<.05 *p<.1

The one predictor logistic model is fitted to the data to test the research hypotheses regarding the relationship between credibility and compliance with the speed limit. According to the model test in Table 6, the positive coefficient for the credibility score predictor suggests that all other variables being equal, the log of the odds of a driver perceiving speed limit credibility level is positively related to compliance with the speed limit. In other words, the higher the credibility rating, the more likely the driver is to comply with the speed limit. For every unit increase in credibility score, the log odds of compliance with speed limit increases by α constant. The three relationships have an odds ratio>1, which means increased speed limit credibility is associated with higher odds of speed limit compliance.

A credibility score with a higher p-value suggests a weak association of credibility with the probability of compliance with the speed limit. However, credibility score is a significant predictor of compliance with the speed limit+10% (p<.1) and compliance with the speed limit+20% (p<.05). As the speed limit threshold gets higher, the significance level of the compliance odds increases. For the model summary, the -2log likelihood is a descriptive measure of goodness-of-fit. The mode of relationship between credibility and compliance with the speed limit+20% fits better than the other models. In addition, the likelihood ratio chi-square with a p-value <.05 shows that the model as a whole fits significantly better than an empty model without predictors.

Therefore, the probability for compliance with speed limit can be expressed as

$$\frac{e^{\wedge}(\alpha \text{ constant} + \beta \text{ credibility} * \text{CREDIBILITY SCORE})}{1 + e^{\wedge}(\alpha \text{ constant} + \beta \text{ credibility} * \text{CREDIBILITY SCORE})} \quad (5)$$

Applying Equation 5, the marginal effect indicates that as the average credibility score increases by 1, the probability of compliance with the speed limit increases by 0.1; the probability of compliance with the speed limit+10% increases by 0.18; and the probability of compliance with the speed limit+20% increases by 0.23. The relationship between credibility score and probability of compliance with speed limit of the three different thresholds is plotted in Figure 4. The credibility value ranges from very non-credible (0) to very credible (100). Larger credibility values are associated with higher probabilities of driver compliance with the speed limit. If the speed limit credibility changes from very non-credible to very credible, there is an 8% increase in compliance with the speed limit, an 18% increase in compliance with the speed limit+10% and a 24% increase in compliance with the speed limit+20%.

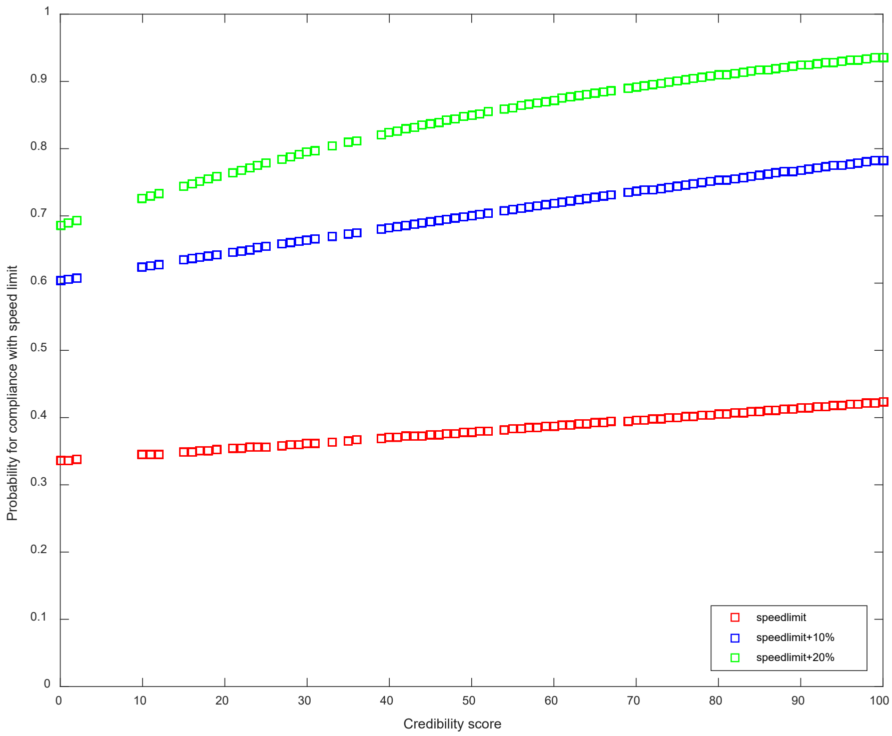

Figure 4 The relationship between speed limit credibility and the probability of driver compliance with the speed limit

Four practical conclusions can be drawn from the relationship.

- First, these results confirm the SWOV (2012b) comments that credible speed limits are supposed to result in drivers obeying speed limits more.
- Second, as the threshold increases, the slope of compliance level increases. It can be seen that a credible speed limit has an important effect on compliance with the speed limit. If the speed limit is more credible, some speed limit offenders are more compliant with the speed limit, thus extreme violations go down.
- Third, there is a notable issue that even if the credibility score is 0, there is still a 35% probability of compliance with the speed limit. This means obedient drivers generally comply with the speed limit regardless of the speed limit credibility.
- Fourth, credibility is a factor that affects compliance, but not the only factor. For practical implementation, it is possible that a more credible speed limit perceived by drivers encourages more compliant and less reckless driving, which, in turn, should lead to a decrease in road accidents and fatalities.

5 Discussion

5.1 Theoretical model justification

The study investigates the relationship between speed limit credibility, risk perception and compliance with speed limit for a given rural single carriageway road layout and roadside environment. The results justified that:

- Higher risk perception has a positive influence on compliance with speed limits.
- Credible speed limit has a positive influence on compliance with speed limit. more credible speed limits can make speeding drivers slow down, especially extreme offenders.
- Greater feeling of risk at a given speed has an influence on feeling that speed limit is too high (less credible).

This result confirms the SWOV (2012b) comments that credible speed limits are supposed to result in drivers obeying speed limits more. More credible speed limits can make speeding drivers slow down, especially extreme offenders. A credible speed limit has an important effect on compliance with the speed limit. If the speed limit is more credible, most of the speed limit offenders will be more compliant with the speed limit, thus extreme violations will go down. Credibility is a factor that affects compliance, but not the only factor. Other various factors affect compliance as well. It is noted that both road type and speed limit are taken into consideration, which indicates that both speed limit credibility and risk feeling are the main factors for compliance with the speed limit.

For the relationship between risk perception and speed limit credibility and speed limit compliance, as drivers feel more risk in a given road environment, they might decrease their speed and perceive the speed limit as less credible. When the speed limit is more credible, drivers are more compliant with the speed limit. This result has confirmed the proposition of Fuller (2005) and Taylor (1964) that feelings of risk provide an input to the decision mechanism from which speed choice is determined.

In addition, the structure and properties of the multilevel models are usefully exploited to investigate the relationship between risk perception and driving speed, and risk perception and speed limit credibility, including the explanatory effects of speed limit, road type and individual driver. Logistic regression is suitable for investigating the relationship between credibility and compliance with the speed limit.

5.2 Methodology justification

In terms of risk feeling task in an automated driving condition in the driving simulator, the human perceptual system integrates data from the visual, vestibular and proprioception systems (Kemeny and Panerai, 2003). The visual system provides the most information about the environment, not only distinguishing between speed and contrast information but also using spatial frequency to judge the speed of moving objects (Kemeny and Panerai, 2003; Jamson et al., 2008). Drivers estimate the motion (speed) of all surface elements in the world by analysing visual input through a process called optic flow (Gibson, 1986). Optic flow and active gaze strategies have both been shown to supply data for self-motion assessment (Kemeny and Panerai, 2003), which plays an important role in the detection and estimation of scene-relative object movement during self-movement. In Task 2, although the 40mph scenes cover a shorter distance than the 50 and 60mph scenes in a given 15 seconds stimuli, drivers risk perception was assumed not affected by the distance, but affected by the visual time.

5.3 Practical implications for road design

There are practical implications for road design. The research provides advice to local highway authorities on matching credible speed limits to rural single carriageway infrastructure in order to provide safe conditions for all road users, supported by evidence. In the decision on the appropriate speed limit, safety is the most important criterion. If the speed limit is not supported by the features of the road and the road environment (i.e. speed limit is not credible), measures are needed to match the road (environment) with the safe speed limit.

5.4 Limitations

There exist limitations of this study. First, speed limit credibility was assessed based on static images in Task 1. The questions for the subjects were fairly technical. Participants in the survey may have a particular interest in the questions. Such proclivities may lead to inaccuracies in the data which cannot be avoided. Second, the research only focused on four parameters in experiment method model, affecting the model integrity. For risk perception, speed limit credibility and speed limit compliance, only one measurement of each were tested. Other measurements could be tested to expand the existing model.

6 Conclusion

The research developed a subjective measurement of speed limit credibility, a subjective measurement of risk perception and an objective measurement of compliance. Consequently, in a given rural single carriageway environment, the hypotheses test there is a significant relationship between risk perception and credibility, risk perception and compliance, and credibility and compliance. A credible speed limit has an important effect on compliance with the speed limit. It is noted that both road type and speed limit are taken into consideration, which indicates that both speed limit credibility and risk feeling are main factors in compliance with the speed limit.

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