THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

RISK, SPEED, AND COUNTERMEASURES ON RURAL NEW ZEALAND ROADS

Prepared for the AA Research Foundation

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Executive Summary

The idea that drivers' perceptions of risk while driving affects their decisions and choices, particularly as regards their speed, is at the heart of many years of our education, engineering, and enforcement strategies to improve road safety. Previous research by ourselves and others has shown that drivers do form fairly consistent judgements about the risk of the road and traffic situations they encounter, but the accuracy of those judgements is low for several specific situations. In particular, our earlier research for the NZAA Research Foundation showed that drivers significantly underestimated the risk of intersections and roadside hazards (i.e., ditches and power poles). Our findings from that research also showed that horizontal curvature, lane width, shoulder width, vertical curvature and separation from on-coming traffic explained around 80% of the driver's perception of risk on rural state highways.

These findings received considerable interest from both road safety professionals and driver behaviour researchers and were reported at two international conferences and published in an international peer reviewed journal (Charlton, Starkey, Perrone, & Isler, 2014). In order to build on that previous research, the researchers, funders, and stakeholders (NZTA) met to define the focus of a follow-on investigation into how perceptions of risk affect drivers' choice of speed on rural roads. Based on these discussions, a research plan was developed to investigate how low-cost countermeasures currently in use on rural roads (road markings and signs) influence drivers' perceptions of risk and the speeds they choose to drive in their presence.

Specifically, the research was designed to answer the following questions:

1. What are the effects of rural road countermeasures on drivers' perceptions of risk?

2. What speeds do drivers choose to drive in the presence of rural road countermeasures?

To answer these questions, 75 participants were recruited to "drive" a video of rural roads in our laboratory and indicate what speed they would drive these roads in their own cars (by using the accelerator and brake pedal in the driving simulator), and then during a second showing of the video, to indicate the level of risk they would feel while driving the road (using a risk meter as in Charlton et al, 2014). The videos contained several road conditions of interest, including four types of road median (dashed white lines, double yellow lines, wide centre lines, and wire rope barriers) as well as roads with different lane widths, high crash area signs, and a police car with flashing lights.

The results showed that the answer to the first research question was a qualified “yes”. Results from regression analyses indicated that high risk ratings were associated with choice of lower speeds. Similarly, when specific road conditions were examined, (e.g., presence of a police car and narrow lanes) it could be seen that when drivers’ ratings of risk increased, their choice of speed decreased. However, other comparisons showed that participants also chose lower speeds for reasons other than increased risk (e.g., speed limits), and increased their speeds in the absence of perceived reductions in risk (wide lanes). In these cases high and low speeds were not differentiated by drivers’ perceptions of risk.

As regards the second question, the results suggest that simple centre line markings can alter drivers’ perceptions of risk, particularly under high traffic conditions. Double yellow centre lines and wide centre lines were perceived as more risky than dashed white centre lines, and under high traffic conditions, this effect was even more pronounced. Perhaps even more significantly, under high traffic conditions the double yellow markings resulted in significantly lower speed choices. In contrast, drivers’ perceptions of risk and speed choices were very stable in the presence of wire rope median barriers; showing little change from low traffic to high traffic conditions.

To provide another look at how rural road countermeasures affect drivers’ speeds and perceptions of risk, another group of 42 participants were recruited to either 1) drive a 50 km loop on rural roads containing several countermeasures of interest (23 participants), or 2) drive the same roads in the simulator using an HD video showing the same 50 km loop (19 participants). The participants’ speeds were continuously recorded and they were asked to provide risk ratings at 14 predetermined locations by a passenger (in both the car and in the simulator).

The results from the 50 km loop mirrored the earlier results; Double yellow lines and wide centre lines produced significant speed reductions and increases in risk ratings compared to dashed white control roads (across a mixture of traffic levels). Further, narrow roads resulted in significantly reduced speeds and increased risk ratings, as did one-lane bridges and level crossings. Finally, at a few locations on the 50 km loop, drivers’ speeds were slightly slower than the drivers in the simulator, but at most locations, and overall there were no statistically significant differences in on-road and simulator speeds. The differences that did exist appeared to be the result of weather conditions and other traffic which could not be controlled for the on-road drivers.

As regards the implications of the research, there are some clear suggestions regarding treatments that could be useful as on-road countermeasures, albeit how and why they work are open to some interpretation. Double yellow lines currently produce higher risk ratings, possibly because of their existing association with a range of high risk situations such as sharp curves and limited forward visibility. Their effectiveness in producing perceptions of risk and reductions of speed is greatest under high traffic situations. A question to be asked is whether more frequent application of these lines, under a wider range of road conditions would lead to any lessening of their effectiveness.

Wide centre lines also have considerable potential as an indicator of high risk roads, and carry along with them the added benefit of increasing the physical separation of oncoming traffic, and frequently are produced by decreasing the widths of the lanes in each direction (another road condition associated with increased risk and lower speeds). As currently implemented, the wide centre lines may produce some increased perceptions of risk simply because of their novelty and the reduction in lane width; there has not been any systematic attempt to “brand” them as an indicator of high risk. In making them even more effective in this regard, delineating wide centre lines with solid yellow lines could offer some compound benefits; reduced lane width, association with risk, and preventing drivers from treating the centre as an overtaking lane.

The use of “High Crash Area” signs did have significant effects reducing speed and increasing perceptions of risk, but the size of those effects were very small in comparison to the effects produced by a police car present on the side of the road. Further work comparing how long-lasting these two interventions are would be of considerable interest.

Risk, Speed, and Countermeasures on Rural New Zealand Roads

1. Background

Understanding why drivers drive the way that they do is a necessary prerequisite to developing a safe road transport system, whether it is by engineering safer vehicles and roads, or whether it is by implementing more effective education and enforcement . The idea that drivers' perceptions of risk play an important role in guiding their on-road behaviour has been central to driver behaviour research for many years (Fuller, 2005; Gibson & Crooks, 1938; Näätänen & Summala, 1974; Taylor, 1964; Watts & Quimby, 1980; Wilde, 1982).

Early models of driver risk proposed that drivers adjust their speed and lane position according to a perceived "field of safe travel" (Gibson & Crooks, 1938) and that departures from the safety zone were associated with increasing levels of emotional tension or anxiety (1964). These ideas were elaborated into the Theory of Risk Homeostasis (Wilde, 1982, 1988, 2002). This theory proposed that drivers possess an internal, target level of risk and they will increase or decrease the safety of their driving in order to reduce the difference between their momentary perceived level of situational risk and their target level.

Several other driver behaviour models featured risk as a central factor in determining drivers' speed choices and many other aspects of their real time decision-making. Rather than simply adjusting speed to the perceived risk of a collision, these models included a somewhat broader range of motivations and moment-to-moment influences on driver behaviour. For example, Näätänen & Summala's Zero Risk Model (1974; 1976) proposed that a driver's decisions are governed by the balancing of inhibitory motives (subjective risk) and excitatory motives. Only when a critical threshold of subjective risk is exceeded, typically through the violation of learned safety margins, it affects on-going behaviour in a way to reduce the driver's experience of subjective risk.

Similarly, Fuller's Task-Capability-Interface Model and its associated Risk Allostasis Theory (2005; 2008) assumed that feelings of risk, not perceptions of collision likelihood guide drivers' decision making. In this approach, drivers try to maintain a preferred level of task difficulty, predominantly by manipulating their driving speed, and their preferred level of difficulty is assumed to vary somewhat depending on their goals and motivations. Driving difficulty in turn is determined by a driver's capability and by the current demands of driving; if the task demands exceed the capability of the driver, then high levels of task difficulty are experienced and the driver will slow down to avoid losing control of the vehicle.

Laboratory and on-road tests, however, have shown that drivers' perceptions of risks and hazards is not always accurate. An early study in which drivers recorded their moment-to-moment judgments of risk by means of an "apprehension meter" while watching a film of highway driving showed that drivers with poor driving records in real life showed poor levels of caution in the laboratory (Pelz and Krupat, 1974). Similarly, on road tests have shown that there are many situations where risks are underestimated or overestimated by drivers (Watts & Quimby, 1980; Kanellaidis et al., 1994, 2000). These authors suggested that differences between actual risk and perceived risk were associated with increased accident frequency, and that where subjective risk is viewed lower than the objective risk the presence of warning signs becomes most important in maintaining adequate safety margins.

More recently, we used both laboratory and on-road tests to examine how accurately drivers perceive risk while driving (Charlton, Starkey, Perrone, & Isler, 2014). To do this, we compared drivers' continuous perceptions of risk to an independent measure of the risk associated with those roads (using road protection scores from the KiwiRAP database). High-definition videos of rural roads, filmed from the drivers' perspective, were presented to 69 participants seated in a driving simulator while they indicated the momentary level of risk they were experiencing by moving a risk meter mounted on the steering wheel. Results showed that drivers' perceptions of risk were generally in agreement with the objective risk, but that certain road situations were perceived as being riskier than the objective risk, and perhaps more importantly, the risk of other situations was significantly under-rated. Horizontal curves and narrow lanes were associated with over-rated risk estimates, while intersections and roadside hazards such as narrow road shoulders, power poles and ditches were significantly under-rated. Analysis of eye movements indicated that drivers did not fixate these under-rated objects. An analysis of the road design elements at 77 locations in the video revealed five road characteristics that predicted nearly 80% of the variance in drivers' risk perceptions; horizontal curvature, lane and shoulder width, gradient, and the presence of median barriers.

The implication of this research for rural highway design was that if drivers were assisted to better recognise the risk of hazardous rural roads, an improvement in drivers' safety would result. Thus, an experiment was conceived to determine how drivers' perceptions of risk are related to the speeds they choose, and identify road features that increase perceived risk and reduce speeds.

2. Research goal and approach

The goal of the present research was to investigate the relationship between drivers' perceived levels of risk on rural NZ roads and the speed they would choose if they were driving those roads as well as determine the influence of specific road features on drivers' speed and perceived risk.

The rural road countermeasures to be tested were selected by the Steering Group for the project, which consisted of researchers and practitioners representing the NZ Transport Agency, the AA Research Foundation, and Opus Central Laboratories. The group identified four types of median treatment to be compared: 1) standard dashed white centreline markings (used as the control or "baseline" condition), 2) double yellow lines; 3) wide centre lines, and 4) wire rope median barrier. These treatments represented an escalating set of countermeasures that are typically applied to rural roads in NZ. Examples of each of the median countermeasures are shown in Figure 1.

Figure 1. The four median treatments selected for testing. Clockwise from top left: Dashed white control, double yellow, wire rope barrier, wide centreline.

In addition to the median countermeasures, the group selected two types of explicit risk/speed warning treatments; "Slow Down - High Crash Area" signs and a police car stopped on the road side. Finally, the effect of road width (narrow vs wide vs control) on speed and risk ratings were compared to speeds and risk ratings associated with rural 70 km/h speed limit zones.

In order to address the research goal, the following research questions were formulated:

1. What are the effects of rural road countermeasures on drivers' perceptions of risk?

2. What speeds do drivers choose to drive in the presence of rural road countermeasures?

In order to address these two research questions a range of complementary research methods, including both laboratory and on-road methodologies, were employed as shown in Figure 2. As can be seen in the figure, the research tasks provided complementary ways of obtaining measures of speed and subjective risk and were selected to provide a degree of cross-validation of the methods. For example, the on-road methodology was used to collect driving speeds and risk ratings in the context of a 50 km loop. This was done in order to ensure that the results obtained from the individual locations in the simulator were generalizable to longer drives on real rural roads. An additional control condition showed drivers the same 50 km loop in the simulator. This final control condition was included to assess whether there were differences in speed and risk that resulted from a long drive as compared to a series of short clips.

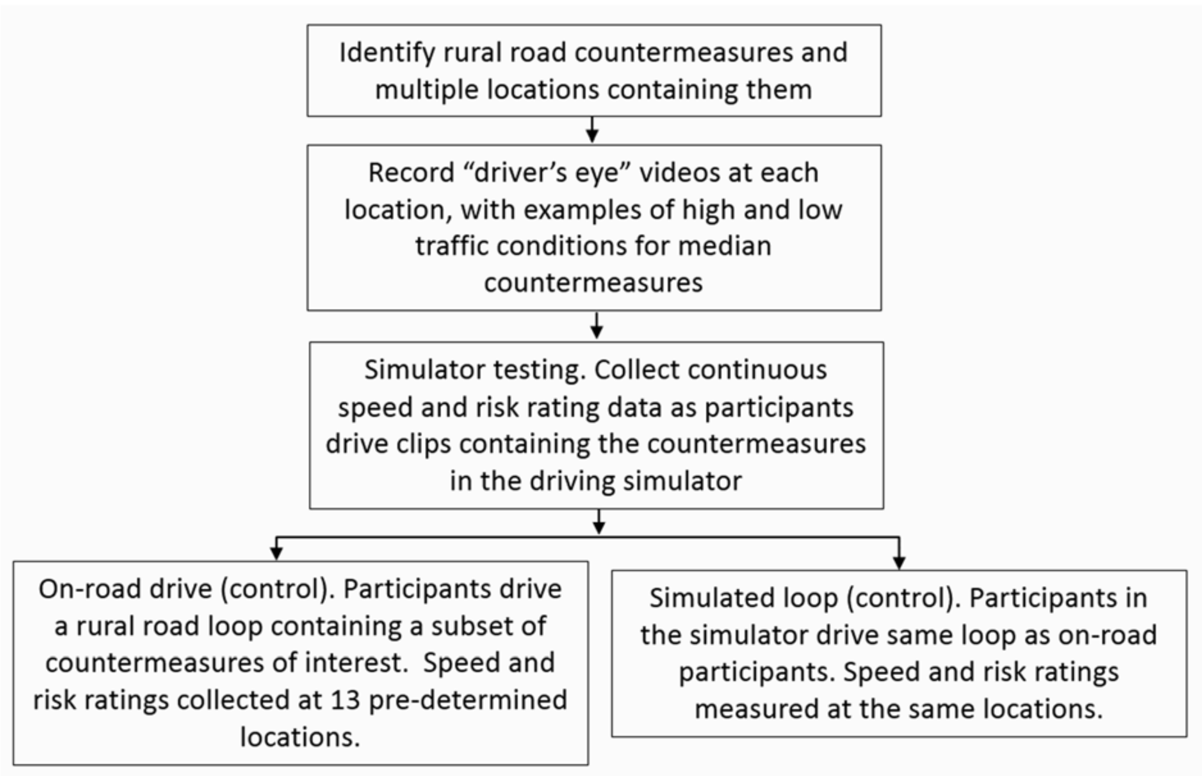

Figure 2. An overview of the research methods used to answer the research questions.

3. Laboratory testing

The goal of this portion of the research was to investigate the relationship between drivers' perceived risk levels and their choice of speed on rural roads. Of particular interest were the participants' speed choices and risk ratings for sections roads containing four common median treatments (dashed white lines, double yellow lines, wide centre line and wire rope barrier) under high and low traffic conditions. In addition drivers' speed and risk ratings in response to two speed warnings (a high crash area sign and a police car) and roads of different width were compared to roads with a reduced speed limit.

3.1. Method

3.1.1. Participants

Seventy five participants with full (unrestricted) NZ driving licences were recruited from notices on community bulletin boards and social media to take part in the study. The 75 participants (37 males; 38 females) had an average age of 34.71 years (range 18-58 years, *SD* = 12.04), and reported an average of 17.04 years since receiving their full NZ licence (range 1-45 years, *SD* = 12.39). Ten of the participants (13.3%) reported receiving a driving infringement (including speed camera ticket) in the past 12 months, one of whom received two, and five participants (6.7%) reported being involved in a motor vehicle crash in the past year (one as a passenger only).

Ethical approval for the recruitment and test protocols was received from the School of Psychology Research Ethics Committee at the University of Waikato. Each of the participants received a $20 gift voucher for participating.

3.1.2. Apparatus

Participants were seated in the AC/TARS driving simulator consisting of a complete automobile (2010 Toyota Prius plug-in) positioned in front of three angled projection surfaces (see Figure 3). The centre projection surface was located 2.32 m in front of the driver's eye position with two peripheral surfaces connected to the central surface at 52 degree angles. The entire projection surface was angled back away from the driver at 4.3 degrees (from the bottom to the top of the projection surface) and produced a 178.2 degree (horizontal) by 33.7 degree (vertical) forward view of the simulated roadway from the driver's position. The image projected on the central surface measured 2.6 m wide by 1.47 m high (at a resolution of 1920 by 1200 pixels) and each of the two peripheral images measured approximately 2.88 m by 2.15 m (at resolutions of 1024 by 768 pixels). In addition, two colour LCDs with an active area of 12.065 cm by 7.493 cm each at a resolution of 640 by 480 pixels were mounted at the centre rear-view mirror and driver's wing mirror positions to provide views looking behind the driver's vehicle. For the present experiment, only the central projection screen was used and the simulated vehicle speeds were presented to the driver on a 16 cm by 9 cm LCD screen located on the central console. Participants' control actions (accelerator, brake, and steering wheel position) were recorded continuously via the vehicle CAN bus. Moving the steering wheel produced a sensation of apparent steering by adjusting the position of the central part of the scene (i.e., the road) on the centre projection screen in real time. The accelerator and brake pedals increased or decreased the speed of the video, and the equivalent vehicle speed (in km/h) was displayed on the centre console display. Cameras were mounted behind the passenger seat and on the dashboard of the vehicle to record other aspects of the participants' behaviour during the experimental sessions.

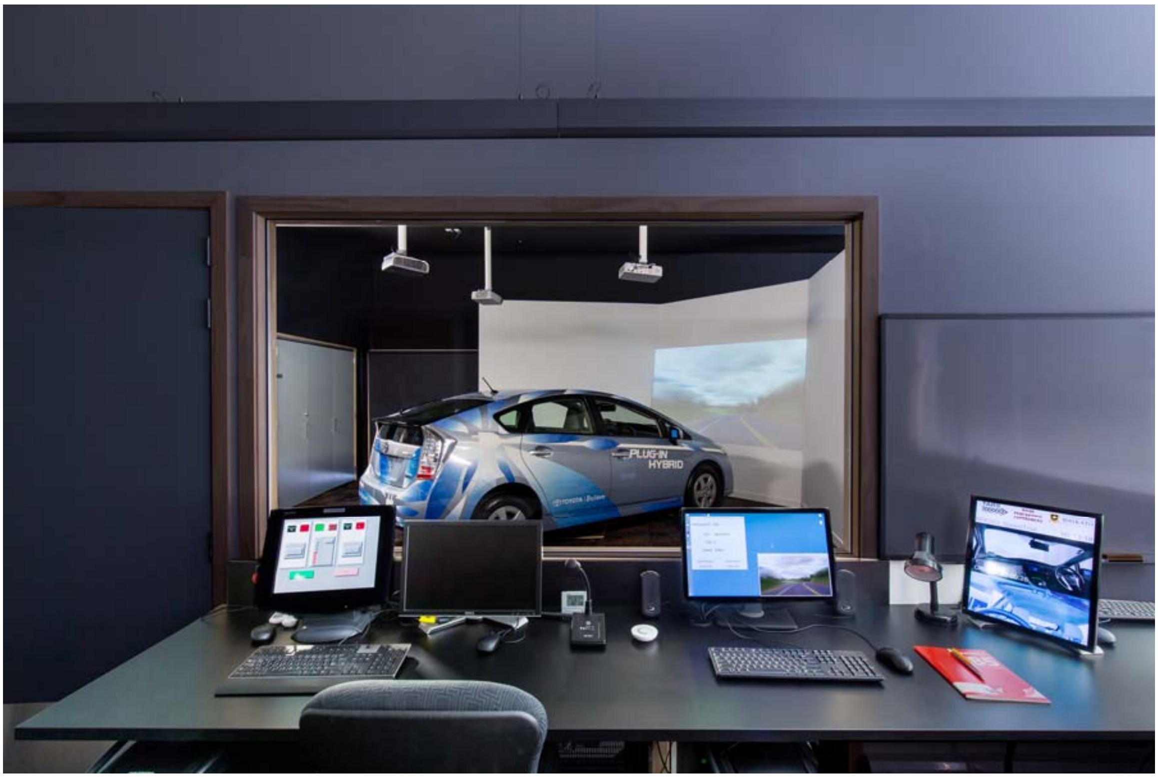

Figure 3. The AC/TARS driving simulator as viewed from the experimenter's station.

3.1.3. Stimulus selection

A total of 15 rural roads in the region that contained the road markings of interest were identified and high-definition video (HD resolution, 60 Hz frame rate) of the roads were collected from a video capture vehicle driven at the posted speed limits (predominantly 100 km/h) in a safe (i.e., non-aggressive) driving style by an experienced driver. The roads were filmed multiple times in order to capture each of the locations with both high and low levels of oncoming traffic. Situations where the speed of the video capture vehicle was impeded due to heading traffic were discarded. A final set of 25 videos was selected such that there were multiple locations containing the median road markings and treatments of interest (i.e., dashed white lines, double yellow lines, wide centre lines, and wire rope barriers) under both high and low traffic conditions. The videos also contained several other road conditions of interest, such as a police car, crash area warning signs, and speed reduction signs, but these were not recorded under both high and low traffic conditions. Each of the videos, with accompanying car and road sounds, was edited into a series of 1 min "clips" or test stimuli and joined into a 25 min test video in which each clip was separated from adjacent clips by a 1 sec interval which dissolved from the clip to black and then to the next scene. The resulting video contained a total of approximately 38 km of driving across the 25 road locations and containing a total of 40 points of interest for measurement. The mean vehicle speed shown in the resulting clips was 91.03 km/h with a modal speed of 97.0 km/h. A 3 min training video containing three clips not used in the test stimuli video was created and used during participant familiarisation.

3.1.4. Procedure

On arrival at the laboratory participants provided written informed consent and completed a brief demographic questionnaire. They were then seated in the simulator and asked to "drive" the video clips while steering and continuously adjusting their speed (using the accelerator and brake pedal). The participants were given an opportunity to practice this in a 3 min training video (composed of three 1 min video clips) that they could repeat until they felt ready to begin the first trial, the speed choice task. During this trial the 25 min video was shown and the participants were asked to continuously adjust their speed to a level that they would comfortable driving on the road in their own car.

A short break followed completion of the first trial and was followed by the second trial, the risk rating task. During this trial, the participants viewed the same 25 min video and provided moment-to-moment judgments of driving risk by means of a risk meter. The risk meter consisted of a small thumbwheel mounted on the steering wheel that controlled a pointer on a risk scale overlaid on the right hand side of the driving scene (see Charlton, Starkey, Perrone & Isler, 2014). The scale anchored with the words "Safe" at the bottom and "Unsafe" at the top with nine calibration lines between and recorded the participants' momentary risk ratings as a continuous variable.

The first 23 participants to complete the risk rating task (11 male, 12 female, mean age 34.78 years) viewed the video at the speed it was recorded while giving their risk ratings and steering; i.e., they could not alter the speed of playback using the accelerator and brake pedals. The remaining 52 participants (26 male, 26 female, mean age 34.67 years) were shown the video clips at the speed they chose during the first half of the session (a "linked" condition). The change to the linked condition was made in order to make the risk ratings more directly comparable to the speed choices made by the participants. The participants (in both the unlinked and linked conditions) practiced the risk rating procedure with the same three practice clips as the first half of the session, and then completed their risk ratings with the 25 clip test video. At the end of the video the participants were thanked with a $20 gift voucher.

3.1.5. Data analysis

Speed and risk data for two participants in the linked condition and risk data for another linked condition participant and two unlinked condition participants were incomplete or not usable due to reported eyestrain, dizziness, or language difficulties, leaving a total sample size of 73 for analyses of speed choice, and 70 for analyses of risk ratings. At each of the 40 pre-determined measurement points in the video each participant's speeds and risk ratings were calculated as averages over 10 sec of driving.

To answer the first research question, whether ratings of high risk were always accompanied by choice of lower speeds, an overall correlation of each participant' risk and speed ratings at each of the 40 measurement points was calculated. However, because this approach did not reflect the within-subjects aspect of the experimental design (and the potential issue of assuming compound symmetry) we also calculated a correlation of speed choice and risk rating at each of the 40 measurement points averaged across all participants (as per Charlton, Starkey, Perrone, & Isler, 2015).

The focus of the analysis for the second research question was a comparison of the participants' speed choice and risk ratings for the each of the principal road median treatments (dashed white lines, double yellow lines, wide centre lines, and wire rope barrier). The risk and speed ratings were averaged across the 2-3 locations containing these treatments separately for the high and low traffic conditions. Data were analysed with a 2 x 4 x 2 mixed-design factorial Anova comparing the participants' performance in the unlinked and linked conditions, the four types of road treatments, under high and low traffic conditions. The results of this analysis for participants' speeds did not indicate any significant difference between the unlinked and linked procedure; [$F(1,71) = .263$, $p = .610$, $\eta_p^2 = .004$]. The same analysis conducted on the participants' risk ratings also failed to reveal any significant difference between the unlinked and linked procedures; [$F(1,68) = 1.77$, $p = .188$, $\eta_p^2 = .025$]. As a consequence of these results, the data for the participants in the unlinked and linked conditions were combined for subsequent analyses. These analyses consisted of 4 x 2 repeated-measures factorial Anovas comparing the four principal road treatments under high and low traffic conditions, and 2 x 2 Anovas comparing other road features of interest such comparisons of speed limit signs and risk warnings.

Finally, individual differences in risk perceptions and speed choices were assessed by means of a multiple regression analysis predicting participants' speeds and risk ratings from the demographic measures.

3.2 Results

The relationship between mean speed choices and risk ratings is shown in the overall scatter plot of the 2,754 speed-risk pairings for all participants at every location (see Figure 4). The relationship between high perceived risk and choice of low speeds is as expected, with higher risk ratings associated with lower speeds, and was statistically reliable [$r(2,753) = -.226$, $p < .001$]. As mentioned earlier, this correlation did not take into account the repeated measures aspect of the design. Because of this, we also calculated the relationship between the mean speeds and risk ratings at each of the 40 measurement locations, and the resulting scatterplot is shown in the right panel of Figure 4. As can be seen in the figure, the significant negative correlation [$r(39) = -.625$, $p < .001$] is even more apparent, such that higher risk ratings were indeed associated with lower speeds. Separate correlations calculated for the unlinked and linked conditions showed the same pattern; $r(39) = -.705$, $p < .001$ and $r(39) = -.569$, $p < .001$, for the unlinked and linked groups respectively, indicating that this relationship held regardless of which of the two procedures was used to collect the speed and rating data.

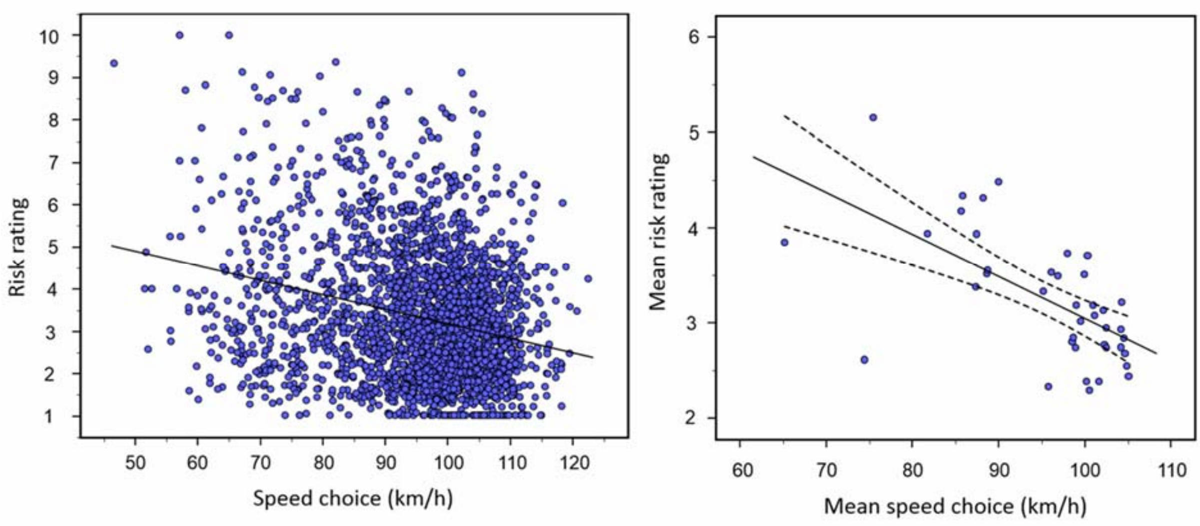

Figure 4. Scatterplots of the relationship between participants' risk ratings and speed choices (left) and the mean risk rating and speed choice for each of the 40 measurement points (right).

The participants' risk and speed ratings for the four median types are shown in Figure 5. As shown in the figure, high traffic was associated with lower speeds overall [$F(1,72) = 464.92$, $p < .001$, $\eta_p^2 = .866$]. There were also significant differences between the four median types [$F(3,216) = 68.11$, $p < .001$, $\eta_p^2 = .486$]. Of even greater interest, however, was the finding of a significant interaction between traffic and median type [$F(3,216) = 39.94$, $p < .001$, $\eta_p^2 = .357$] such that the amount of speed reduction under high traffic conditions was dependent on the type of median present. This pattern can also be seen clearly in Figure 5, the degree of speed reduction was most pronounced for double yellow lines, and least for wire rope barriers. Post hoc pairwise comparisons (Bonferroni-adjusted) indicated that all of the median types were significantly different than one another under low traffic conditions (largest $p = .022$ / ps < .022) with the exception of dashed white and double yellow lines ($p = .630$). Under high traffic conditions all of the median types were significantly different than one another (ps < .023).

A similar pattern can be seen for the participants' risk ratings in right panel of Figure 5. Risk ratings were generally higher under the high traffic conditions [$F(1,69) = 130.21$, $p < .001$, $\eta_p^2 = .654$], there were significant differences between the four median types [$F(3,207) = 25.46$, $p < .001$, $\eta_p^2 = .270$], and a significant interaction between median type and level of traffic [$F(3,207) = 38.67$, $p < .001$, $\eta_p^2 = .359$] indicating that the effect of the medians on drivers' perceptions of risk depended on the traffic conditions. Under low traffic conditions the risk ratings for dashed white lines were significantly lower than all other median types

(Bonferroni-adjusted *p*s < .001). Under high traffic conditions, the risk ratings associated with all of the median types increased, with the exception of wire rope barriers, which remained the same (M = 2.84 and M = 2.90 for low and high traffic respectively). Under high traffic conditions the risk ratings accompanying the other three median types increased and were significantly higher than the wire rope barriers (*p*s < .001) with the double yellow lines producing the greatest increase in risk ratings, to a level significantly higher than all others (*p*s < .001).

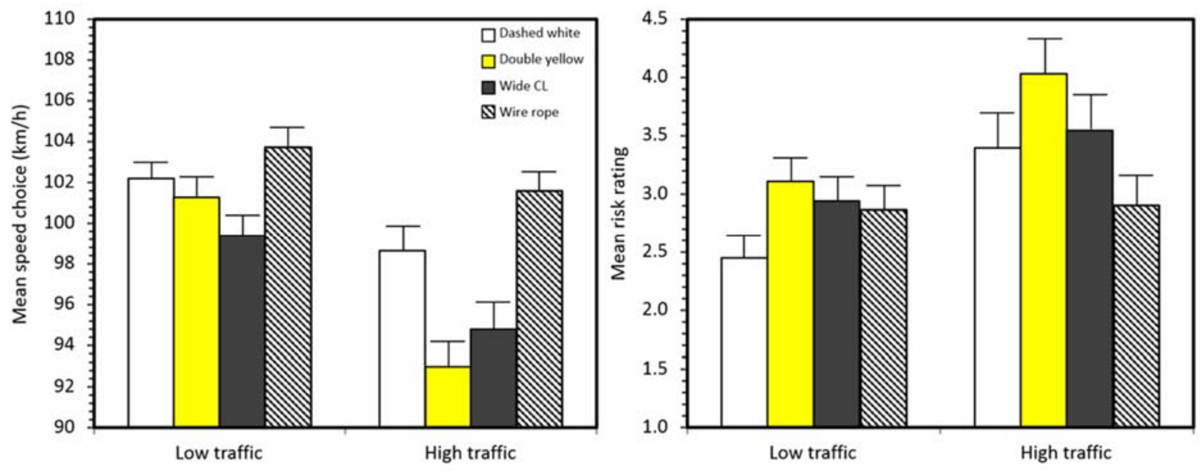

Figure 5. Participants' mean speed choice (left) and risk rating (right) for four median types. Error bars indicate 95% confidence intervals.

The type of median was not the only road condition associated with significant changes in the participants' ratings of risk and speed choices. Figure 6 shows the relative effects of a large "Slow Down, High Crash Rate" sign and a police car with flashing LED lightbar in equivalent locations on the roadside. The figure shows the speeds and risk ratings averaged across the 6 sec prior to them coming into view compared to the average taken in the final 6 sec of the approach to the locations. As can be seen, participants reduced their speeds in response to both condition, but the effect was significantly greater for the police car. A 2 x 2 repeated-measures Anova indicated a significant before-after effect overall, [$F(1,71) = 160.52$, $p < .001$, $\eta_p^2 = .693$], and a significant difference between the car and the sign [$F(1,71) = 67.41$, $p < .001$, $\eta_p^2 = .487$], but most noteworthy was the significant interaction [$F(1,71) = 63.00$, $p < .001$, $\eta_p^2 = .470$], reflecting the substantially larger effect of the police car.

The right panel of Figure 6 shows the parallel effect of the sign and police car on the participants' risk ratings. A 2 x 2 repeated-measures Anova resulted in a significant before-after effect, [$F(1,68) = 50.32$, $p < .001$, $\eta_p^2 = .425$], and a significant difference between the car and the sign [$F(1,68) = 5.16$, $p = .026$, $\eta_p^2 = .487$], and a significant interaction [$F(1,68) = 23.70$, $p < .001$, $\eta_p^2 = .258$], once again indicative of the significantly greater increase in risk ratings associated with the police car.

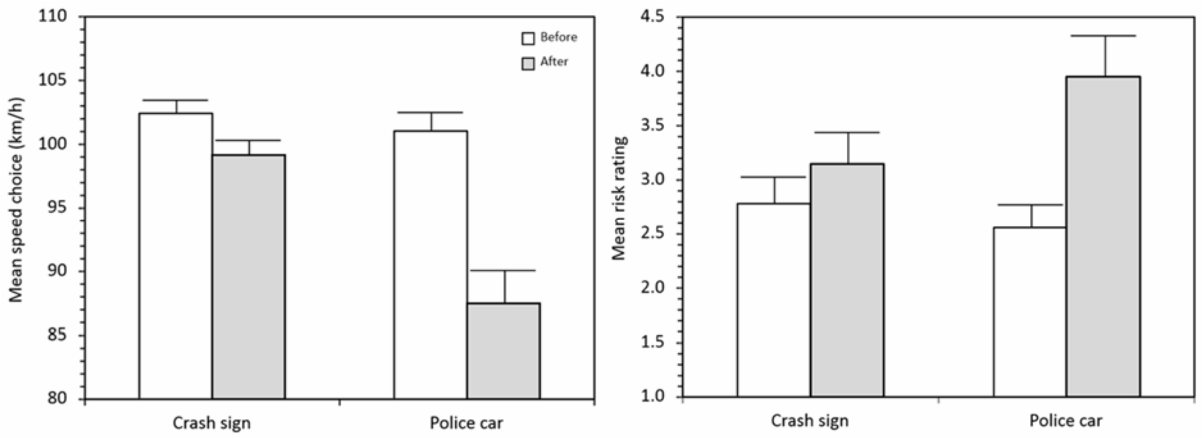

Figure 6. Participants' mean speed choice (left) and risk rating (right) before and after a "Slow Down High Crash Rate" sign and a police car with flashing lights at the roadside. Error bars indicate 95% confidence intervals.

Another aspect of the road environment found to have a substantial effect on the participants' speed choices and risk ratings was the width of their lane. Figure 7 shows the speeds chosen by the participants after passing a sign indicating a posted speed limit of 70 km/h, the average speeds chosen for three narrow roads, the three roads used as a control condition (typical lane width and dashed white median), and three wide roads (> 4 m average lane width). Low traffic conditions were depicted in every instance. A repeated-measures Anova indicated that the speed choices were significantly different for the three road widths [$F(2,142) = 1517.72$, $p < .001$, $\eta_p^2 = .955$] and post hoc pair-wise comparisons indicated that the roads with wide lanes were associated with speeds significantly higher than the control roads ($p < .001$), the speeds for roads with narrow lanes were significantly lower than the control roads ($p < .001$), and not reliably different to the road with the 70 km/h speed limit. The right panel, however, shows that the speed reductions on the narrow lanes were associated with significantly higher risk ratings (Bonferroni adjusted $p < .001$) and an overall significant difference between the three road widths [$F(2,136) = 108.11$, $p < .001$, $\eta_p^2 = .614$].

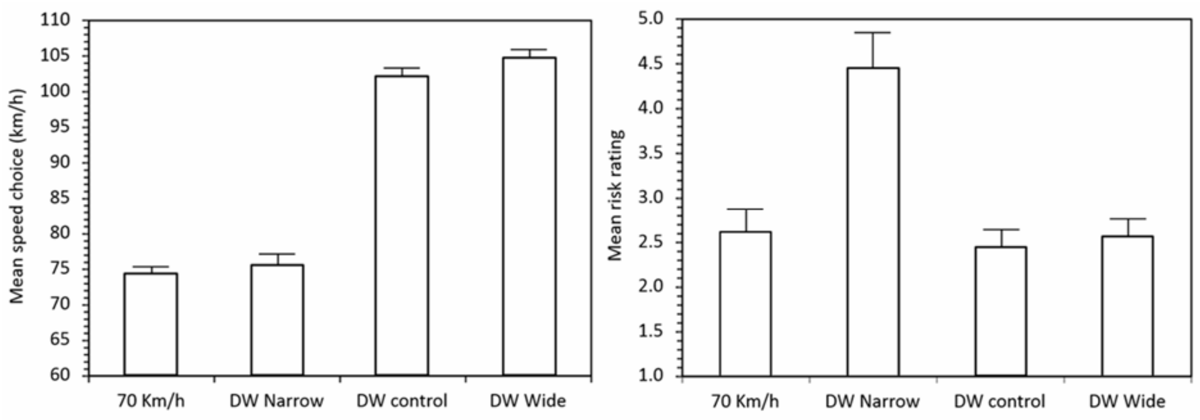

Figure 7. Participants' mean speed choice (left) and risk rating (right) for three different road widths at 100 km/h compared to a 70 km/h speed zone. Error bars indicate 95% confidence intervals.

The relationship between the participants' demographics and their ratings of risk and speed choice were explored with multiple regression but we were unable to identify any significant relationships with the participants' age, experience, gender, or other individual characteristics.

4. On-road testing

The purpose of the on-road testing was to verify whether the same pattern of responses obtained during the simulator testing would be found to occur on-road for similar rural roads. To do this, rural roads containing the road markings and other countermeasures of interest were identified near the university. From there, a loop that could be completed by participants in under an hour was identified. Because the on-road situation differed from the simulator test in that the loop was a continuous drive as opposed to a series of isolated clips, a further control condition was added; the simulated loop in which a group of participants drove the same loop in the simulator. This would allow a more direct comparison of the patterns produced in the simulator and on-road drives, and if necessary provide a calibration or offset to the findings found earlier in the simulator tests.

4.1. Method

4.1.1. Participants

Forty two participants with full (unrestricted) NZ driving licences were recruited from notices on community bulletin boards and social media to take part in the study. The participants (22 males; 20 females) had an average age of 32.83 years (range 18-63 years, *SD* = 14.44), and reported an average of 16.61 years since receiving their full NZ licence (range 1-48 years, *SD* = 14.33). Eight of the participants (19.05%) reported receiving one or more driving infringements (including speed camera ticket) in the past 12 months, one of whom received four, and three participants (7.14%) reported being involved in a motor vehicle crash in the past year. The participants were randomly assigned to one of two groups: an on-road group (n = 23) or a simulator loop group (n = 19).

Ethical approval for the recruitment and test protocols was received from the School of Psychology Research Ethics Committee at the University of Waikato. Each of the participants received a $20 gift voucher for participating.

4.1.2. Apparatus

Participants in the on-road group were seated one of the University of Waikato's fleet of Toyota Prius cars, and participants in the simulator loop group were seated in the driving simulator (2010 Toyota Prius plug-in) described earlier.

4.1.3. Procedure

Participants were asked to drive a 50 km loop of rural roads located near the university. The loop contained thirteen locations with road features and markings of interest as follows: two locations with dashed white centreline (control), two locations with double yellow centreline, two locations with dashed white wide centreline, two locations with double yellow wide centreline, two narrow road locations, two locations with level crossings, and one location with a one-lane bridge.

During the drive, participants were asked to drive their vehicle on the 50 km circuit (either on-road or in the simulator) while accompanied by a research assistant. For participants in the on-road group, they were given some time to get comfortable with the vehicle and practice answering the risk rating questions on the short drive to the beginning of the rural road loop. For the participants in the simulator group, they were given a short practice video for the same purposes. At thirteen predetermined locations on the route, the participants were asked to provide ratings of perceived risk on a scale of 1 to 10. A camera, mounted between the passenger and driver seats recorded the road ahead, the speedometer, and the participants' verbal responses to the questions. Participants were asked to comply with all normal road rules and regulations during the drive.

4.2. Results

Shown in Figure 8 are the participants' mean speed choices and risk ratings at the locations with dashed white, double yellow, and wide centre lines (dashed white or double yellow) for both of the on-road and simulator loop groups. The speeds were averaged at locations with the same type of centreline and then compared with a mixed-design 2 (group) x 4 (line type). This analysis indicated a slightly lower speed for the participants in the on-road group [$F(1,40) = 5.57$, $p = .023$, $\eta_p^2 = .122$]. Looking at the differences between the line types there was a significant main effect of line type [$F(3,120) = 14.21$, $p < .001$, $\eta_p^2 = .262$] as well as a significant interaction between group and line type [$F(3,120) = 4.79$, $p = .003$, $\eta_p^2 = .107$]. Post-hoc pairwise comparisons (Bonferroni adjusted) indicated that speeds for the control marking (dashed white) were significantly higher than the three other centreline types (ps < .027). A similar analysis was performed for the participants' risk ratings (also averaged across the locations with the same centreline type). The mixed-design 2 x 4 Anova did not show any difference between the two groups, [$F(1,40) = 1.34$, $p = .254$, $\eta_p^2 = .032$] but did show a significant difference between the four line types [$F(3,120) = 7.45$, $p < .001$, $\eta_p^2 =$

.157] as well as a significant interaction between group and line type [$F(3,120) = 3.28$, $p = .023$, $\eta_p^2 = .076$]. Post-hoc comparisons indicated that the risk ratings associated with the double yellow lines were higher than the dashed white control ($p = .001$) and the dashed white wide centreline ($p = .016$), but was not significantly different than the double yellow wide centreline ($p = .182$).

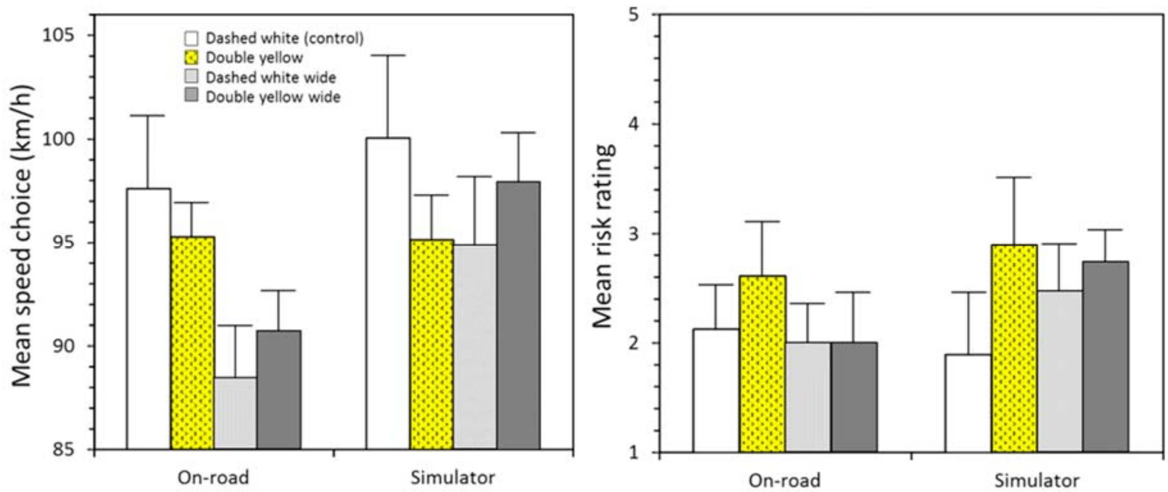

Figure 8. Mean speed and risk ratings for four different types of centreline for the on-road group and the simulator loop group. Error bars indicate 95% confidence intervals.

Figure 9 shows the comparison of speeds and risk ratings for the narrow roads and control roads, as well as for level crossings (two locations) and the one-lane bridge. As with the road markings, the measures were averaged across locations with the same road features (except the one location containing the one-lane bridge). Considering all of these locations there was no significant difference between the on-road and simulator loop groups in terms of either their speeds [$F(1,40) = 0.026$, $p = .872$, $\eta_p^2 = .001$] or risk ratings [$F(1,40) = 1.09$, $p = .303$, $\eta_p^2 = .027$]. As can be seen in the figure, however, there were large differences between the four road types. As regards speeds, the four road types were reliably different [$F(3,120) = 38.31$, $p < .001$, $\eta_p^2 = .489$] and there was a small but significant interaction between group and road type [$F(3,120) = 2.87$, $p = .039$, $\eta_p^2 = .067$]. Post-hoc comparisons (Bonferroni adjusted) showed that the mean speed on the narrow roads was significantly lower than the dashed white control roads ($p = .002$), but significantly higher than the level crossings ($p = .006$) and the one lane bridge ($p < .001$). The one lane bridge was associated with the lowest speeds overall and were significantly lower than the level crossings ($p = .031$).

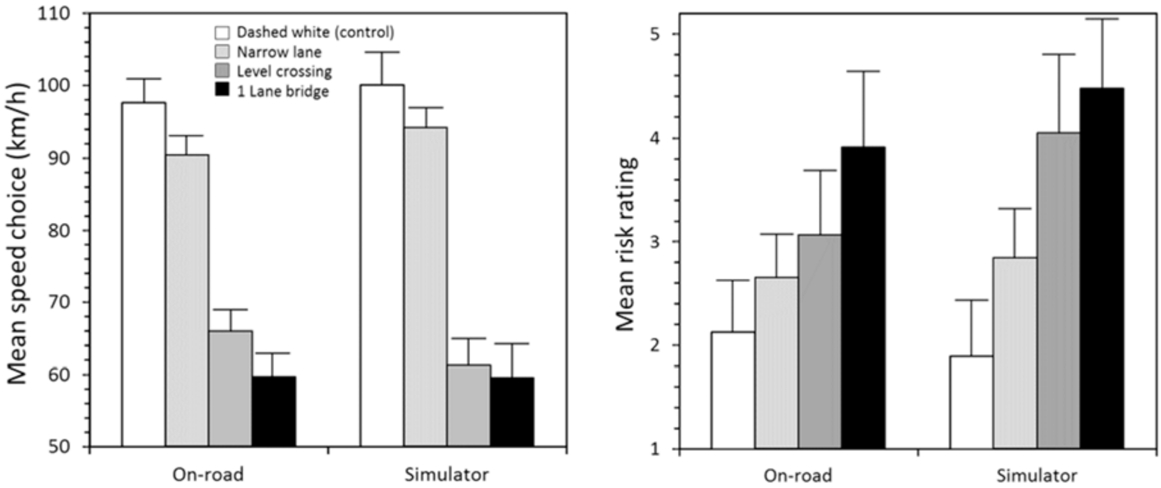

Figure 9. Mean speeds and risk ratings for four different road types. Error bars indicate 95% confidence intervals.

Looking at the risk ratings for these four road types, there was a significant difference between the road types [$F(3,120) = 39.42$, $p < .001$, $\eta_p^2 = .632$] but no evidence of an interaction between group and road type [$F(3,120) = 1.85$, $p = .142$, $\eta_p^2 = .044$]. Post hoc comparisons showed that the one lane bridge had the highest risk ratings (*p*s < .001) and the dashed white control roads had the lowest (*p*s < .001).

5. Conclusions

Returning to the research questions identified at the beginning of the project, the present study provides some useful answers regarding the effects of rural road countermeasures' effects on drivers' perceptions of risk and their speed choices at those locations. Across all of the conditions tested, there were significant correlations between risk and speed, with higher risk ratings associated with lower speeds. This may be due to the fact that in situations of perceived high risk, drivers are inclined to reduce their speeds. In the present experiment, drivers chose slower speeds and gave higher risk ratings when traffic was heavy. Interestingly, the presence of wire rope barriers appeared to mitigate the effects of higher traffic volumes, with drivers selecting similar speeds across both traffic conditions and their risk rating remained low. This suggests that drivers do perceive physical barriers from on-coming traffic as conferring a safety benefit. Areas with double yellow lines and wide centre lines however, appeared riskier to drivers compared to roads with dashed white lines. It is possible of course that drivers were responding to the road per se rather than the median treatment, but we think this is unlikely as roads were matched as closely as possible to ensure they had a similar visual appearance. The presence of a police car led to large reductions in speed and increased ratings of perceived risk. These changes were much greater than those observed in response to a high crash area sign, suggesting that a visible police presence on the roads is an effective way to reduce speeding.

Finally, providing participants with the opportunity to evaluate risk at the speed they chose (the linked condition) resulted in higher ratings of risk compared to ratings given when watching the footage at the speed it was recorded. This increase could be a result of the higher speeds chosen by participants, or it may be an indication that participants are accepting of a higher level of risk (or task difficulty) than the recorded footage allowed. Further research using pre-recorded video presented at varying speeds may help to shed light on this issue.

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