Accident Analysis and Prevention 121 (2018) 250–257

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Transitions within a safe road system

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ARTICLE INFO

Keywords:
Driving schema
Driver expectations
Risk perception
Road categories
Road markings
Speed choice

ABSTRACT

As drivers move through the road transport system they are exposed to a range of different situations and road conditions in a relatively short space of time. Drivers' expectations about what will happen on different types of roads have strong effects on their speed choices, and where they look and what they attend to. As a result it is important to assist drivers to change their expectations when they transition from one road type to another. In this experiment we investigated the effectiveness of different centreline road markings in preparing for a horizontal curve as drivers moved from a motorway to a two-lane rural country road. Fifty individuals were recruited to participate in a video-based simulated driving task to compare three centreline marking types in terms of their effects on speed choice and reactions to a driving hazard (horizontal curve). Although a complex marking previously associated with high risk produced the largest speed reductions during the transition from the motorway, it was the centreline more traditionally associated with rural country roads (dashed white centreline) that was associated with the best hazard reactions post-transition (brake reaction time and speed reduction before a horizontal curve). The findings demonstrated that the look of a road needs to convey a clear and unambiguous message to drivers. The transition to a two-star rural road is best achieved by making the road look like a typical two-star road as soon as possible.

1. Introduction

As drivers move through the road transport system they typically encounter different types of roads, often with different kinds of hazards and levels of safety. With experience, drivers learn what to expect on familiar roads and different types of roads. These expectations are an important part of the everyday driving experience and have a powerful influence on drivers' speed choice, visual search strategy, and preparedness to react to road hazards and traffic situations (Briggs et al., 2018; Charlton and Starkey, 2013, 2016; Martens and Fox, 2007; Young et al., 2017).

Although these expectations are generally beneficial to safe and efficient driving, they can contribute to errors when the expectations are inappropriate for the current conditions or road type. Across a wide range of experiments it has been shown that drivers often look but fail to see road signs, other road users, and other important traffic information, because the information had recently changed, it was not in the usual location, or simply because it was not what they expected to see (Borowsky et al., 2008; Harms and Brookhuis, 2016; Martens and Fox, 2007; Young et al., 2017). The effect of these incorrect expectations, in essence a type of mode error (Sarter and Woods, 1995), can range from an incorrect turning at an intersection, choice of an inappropriate speed, or a crash with another road user.

If, for example, traffic signs are located in unusual places experienced drivers often fail to notice them (Borowsky et al., 2008). It has been suggested that this form of inattentional blindness, also called selective looking, results from the development of schemas that guide experienced drivers' visual scanning of the roadway (Borowsky et al., 2010). In one recent study, a professional driver wore eye tracking glasses over the course of 28 repetitions of an 18 km loop (Young et al., 2017). As her familiarity with the route grew, the driver's looking behaviour changed substantially, and overall there was an increase in the amount of time spent looking at non-road relevant areas.

To better understand drivers' schemas for rural roads, Gundy, 1994 conducted a series of studies in which participants were asked to sort photographs of roads into piles that were similar to each other and different from those in other piles. In some cases participants were asked to label the piles to describe the roads or estimate a safe driving speed for the roads. The participants formed stable road categories that reflected the width of the carriageway and the presence or absence of intersections and curves. Interestingly, the subjective road categories identified by the participants were often quite different from the official engineering categories and legal designations (Gundy, 1994). Using a similar photo sort method in a study of rural roads in New Zealand, we

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https://doi.org/10.1016/j.aap.2018.09.022
Received 24 May 2018; Received in revised form 6 August 2018; Accepted 20 September 2018
Available online 01 October 2018
0001-4575/

found that drivers generally agreed on six non-overlapping categories of rural roads (Charlton and Starkey, 2017a). Importantly, these categories correctly predicted the participants' later ratings of the speed limits, driving difficulty, physical comfort, and safety of the individual roads.

The mental categories and expectations evoked by the look of a road can even over-ride the presence of a speed limit sign. In a study of urban roads (Charlton and Starkey, 2017b), participants drove a video-based simulation of familiar urban roads using the vehicle controls to speed up and slow down. When asked the speed limit on the roads they had just driven, the participants were often wrong, choosing speeds that were consistent with roads that looked similar but had different speed limits.

Roads can also be categorised according to their relative risk by assessing the presence or absence of road features that have previously been associated with crash likelihood and severity; features such as lane and shoulder width or the presence of safety barriers. The International Road Assessment Programme (IRAP) is a large-scale programme to categorise road risks that is being undertaken in several countries in Europe, the United Kingdom, Central and South America, Australia, and New Zealand (Waibl et al., 2012). One of the products of IRAP assessments are ratings in which roads are given different numbers of "stars" for the level of safety they offer, ranging from 1 (low safety/high risk) to 5 (high safety). We have previously shown that drivers' perceptions of risk generally correspond to the IRAP-assessed levels of crash risk, but there are areas where drivers significantly under- or over-estimate the risk (Charlton et al., 2014). In addition to these simple misperceptions of risk, a change from a low-risk road to a high-risk road may pose a significant hazard if driver expectations do not change accordingly. In particular, after driving on a low-risk four or five-star motorway, moving to a two-star rural country road may leave a driver unprepared for risks such as traffic at intersections, sudden changes in horizontal alignment, or even misperceptions of the allowable direction of travel for adjacent lanes.

The idea that drivers' perceptions of risk affect their choice of speed is at the heart of many years of research, as well as driver education and enforcement strategies (Benda and Hoyos, 1983; Kanellaidis et al., 2000; Taylor, 1964). For example it has been shown that when asked to categorise filmed scenes containing a road hazard, young drivers rely on superficial elements of the visible hazard as compared to experienced drivers who used their expectancies about the overall situation to classify the movies, resulting in a more consistent set of categories (Borowsky et al., 2009). The accurate recognition of hazards and its relationship to drivers' choice of appropriate speeds is well known, as excessive speed has been shown to increase the probability of a crash, as well as the severity of crashes that do occur (Elvik, 2013; Shinar, 2017). The link between perception of risk and choice of speed was demonstrated in another video-based simulation (where participants could control their speed) on roads with different types of centre median road markings (dashed white lines, double yellow centre lines, wide centre lines) (Charlton and Starkey, 2016). The participants' speeds in the simulator corresponded with the ratings of the risk they felt on the same roads during a subsequent drive, rating risk higher for the roads they had driven more slowly.

Road markings can be used to influence drivers' speeds in a number of ways other than manipulating perceived risk. Road markings known as perceptual countermeasures, such as transverse lines, dragon's teeth, or herring bones, can be applied at specific locations to slow drivers down as they approach hazardous intersections or curves (Agent, 1980; Denton, 1980; Fildes and Jarvis, 1994; Godley et al., 1999). Some of these markings work by attracting drivers' attention and provide an explicit warning signal, whereas others produce speed reductions by affecting drivers' perceptions of how fast they are travelling (Charlton, 2007; Elliot et al., 2003; Montella et al., 2011). Although these road markings have been shown to produce localised speed reductions for specific hazards, the extent to which they confer a more general or long-lasting safety benefit is much less clear (Charlton, 2007; Denton, 1980; Godley et al., 1999). At issue is how long-lasting the speed-reducing effect of these treatments are. For example, the use of herringbone road markings have been shown to be effective in reducing speeds in the short term, but not always over longer sections of road or drive durations (Martindale and Urlich, 2010).

Road markings can also be used to help drivers discriminate different types of roads, an approach related to the concept of self-explaining roads which assists drivers to make appropriate speed choices more or less automatically (Charlton et al., 2010; Theewes and Godthelp, 1992). An important component of this approach is to help drivers form mental schemata and scripts, memory representations that will lead road users to rapidly identify the type of road they are driving upon and activate appropriate expectations and behaviour (Theewes and Godthelp, 1992). In order to help manage drivers' expectations as they move through the transport system, several attempts have been made to provide accurate and reliable cues regarding road type. In one study, readily recognisable road markings were applied to photos of rural roads and participants were shown photographs showing sections of two road categories with an intersection in between (Stelling-Konczak et al., 2011). In order to determine which road markings would help drivers notice transitions between rural road categories (with different speed limits), the participants were asked to rate the speed limits of the roads shown. The markings were chosen on the basis of their recognisability characteristics and participants were either told about the meaning of the markings beforehand, or not. The results showed that physical separation of lanes with different driving directions was the best cue available for participants to discriminate transitions between distributor and through roads. Transitions between distributor and access roads were more readily recognised when no markings on access roads were present. In a simulator study comparing two recognisable road marking systems to standard road markings, the recognisable markings led to speeds reliably under the speed limit, with no difference between participants who had been told about the meaning of the markings before the simulated drive and those who had not been given any information beforehand (Aarts and Davidse, 2008).

An important and unanswered question is the degree to which indicating a transition from one road type to another with road markings will do more than produce simple localised or short-term speed reductions. In essence, can road markings used during transitions evoke correct expectations and prepare drivers for what lies ahead? As a practical matter, when drivers move from a low-risk motorway to a high-risk rural road can we help drivers to change their mind-set and prepare them to react to hazards? In this case, signalling the transition in road type has a function beyond that of a localised perceptual countermeasure, something more akin to priming an alternative schema or set of expectations.

In order to address this question, the goal of the present experiment was to investigate drivers' transitions from five-star motorways to a two-star rural country roads and their subsequent reactions to hazardous road conditions. Most new motorways in New Zealand are constructed to a "five-star" standard as designated by the IRAP criteria (NZTA, 2014; Waibl et al., 2012). Roads constructed to this standard are divided highways that are predominantly straight, possessing clear line marking, wide lanes and sealed shoulders, safe roadsides and no more than occasional grade separated intersections. In contrast, a two-star road (the predominant rural road type in New Zealand) is described as having poor alignment, poor roadside conditions, narrow lanes, no median protection against head-on crashes, insufficient overtaking provision, and poorly designed intersections at regular intervals. How best to keep drivers safe when they leave the relatively benign conditions of a new five-star motorway and encounter the hazards of the typical two-star rural road was thus of both practical concern and theoretical interest.

In particular we wanted to examine whether signalling this type of transition was best served by providing an alerting or warning cue in the form of an unusual road marking, a marking associated with higher risk to reduce speed, or by simply allowing drivers to adapt their driving to the new conditions and new risks. We used a video-based driving simulation in which drivers habituated to driving under motorway conditions, and followed it by several types of road markings in transition zones; a wide centreline (unusual for these roads), a complex centreline involving no overtaking lines and turn bays (previously shown to be rated as risky, Charlton and Starkey, 2016), and standard dashed white centreline typical of rural country roads. We measured both the immediate effects on participants' speeds as well as their subsequent post-transition reactions to a driving hazard, in this case a horizontal curve. To supplement and extend the simulator findings, participants were also asked to provide ratings of speed choice, safe speed, speed limit, driving difficulty, overtaking safety and overall safety for a series of photographs depicting roads with a variety of road markings.

The specific question posed in this experiment was whether it would be best to signal the change in road type with a conspicuous road marking, a marking previously associated with high risk, or road markings typical of the new road type?

2. Method

2.1. Participants

Fifty individuals with a full New Zealand driver's license completed the study (28 females), with a mean age of 36.58 years (SD = 13.95, range 16–64 years). Participants reported having their driver's license for a period of 18.12 years (SD = 14.87, range 1–49 years). The participants reported driving on average 227.82 km per week (SD = 296.57, range 10–1600 km per week). In terms of driving history, 8 participants reported being involved in a crash at some point during their driving history, out of which 7 reported being involved in 1 crash and 1 reported being in 2 crashes.

The participants were recruited for the study via community noticeboards and electronically via the University communication channels. Ethical approval for the recruitment and test protocols was received from the local research ethics review board. Each of the participants received a $20 gift voucher for participating.

2.2. Materials and apparatus

2.2.1. Road video

High-definition video (HD resolution, 100 Hz frame rate) of rural roads in the Auckland and Waikato regions were collected from a video capture vehicle driven at or just below the posted speed limits in a safe (i.e., non-aggressive) driving style by a professional driver. The roads were chosen in consultation with representatives from the national road authority to be representative of the national network. The roads were filmed multiple times in daylight and dry weather in order to capture each of the locations with average levels of oncoming traffic and to avoid any unusual or distracting events (e.g., hazards created by other vehicles, pedestrians, etc.). Situations where the speed of the video capture vehicle was impeded due to heading traffic were discarded.

The videos, with accompanying car and road sounds, were edited into 15 video clips so that each clip depicted driving scenes with: a clear view ahead (> 6 s headway to leading vehicles), did not overtake slower traffic, contained few or no vehicles travelling in adjacent lanes, and no vehicles parked at the roadside. Each clip was separated from adjacent clips by a 1 s interval which dissolved from the clip to black and then to the next clip. All clips began playback at 100 km/h.

As shown in Figs. 1 and 2, five of the clips depicted Motorway scenes; i.e., four or more lanes of travel with a dividing median, 100 km/h speed limits, and grade-separated intersections. The motorway clips were approximately three minutes in length (M = 184.40 s, range = 168–207 s, SD = 14.36 s).

Five of the clips, called Transitions, depicted two-lane rural roads with 100 km/h speed limits (although no speed signs were included in the clips). These rural roads were unremarkable in that they all contained lanes approximately 3.5 m wide, solid white edge lines (0.1 m wide) and moderate shoulders (varying in width throughout each clip but averaging 0.8). The duration of all of the Transition clips was 70 s, with no horizontal or vertical curves, and they differed in terms of the centre line markings that separated the two lanes. Two contained the "standard" NZ dashed white centre lines (3.0 m dashes, 7.0 m spaces, 0.1 m wide); one contained wide centre lines (two standard dashed white lines in parallel, 1.0 m apart); and one contained a complex centre line that included dashed white, double yellow (no overtaking), directional overtaking (solid yellow on one side, dashed white on the other, and two right turn bays.

The final five clips, called Terminal clips (60 s in duration each) depicted similar two-lane rural roads as described above, with the exception that three of the roads contained curves with advance advisory 55 km/h curve warnings that came into sight approximately 30 s into the clip. The vehicle came abreast of the sign approximately 35 s into the clip, and reached the curve approximately 45 s into the clip (note these times are approximate because during the simulation, participants could control their virtual speed, which affected clip duration). In New Zealand, the advisory speeds for curves are not regulatory (i.e., they are not speed limits). They are determined using road survey vehicles equipped with a "ball-bank indicator" (or "side-thrust gauge") calibrated to produce advisory speeds in 10 km/h intervals (Koorey et al., 2001).

2.2.2. Driving simulator

Participants completed the driving task in a driving simulator consisting of a complete automobile (2010 Toyota Prius plug-in) positioned in front of angled projection surfaces. Details of the simulator have been published previously (Charlton and Starkey, 2017b). For the present experiment the road video clips were shown on a central projection screen (located 2.32 m from the driver and angled back away from the driver at 4.3 degrees). The image projected on the screen measured 2.6 m wide by 1.47 m high at a resolution of 1920 by 1200 pixels. Participants' control actions (accelerator, brake, and steering) were recorded continuously via the vehicle CAN bus. 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 digital dashboard speedometer. 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. Unobtrusive cameras were mounted between the passenger and driver's seats and on the dashboard to monitor and record the participants' behaviour during the experimental sessions.

2.2.3. Questionnaire

A computer-based questionnaire was created to supplement the information gathered from the simulated drive. Participants were provided with high resolution photographs of roads drawn from videos that were not chosen for the driving simulation clips. This included two motorways, two roads with dashed white centre line, two with wide centre lines, and two with flush medians (painted medians approximately 2.0 m wide containing diagonal lines and a solid white outline with 0.1 m lines);. The photos were presented to participants one at a time in a randomised order, and they were prompted to provide three ratings and answer three open-ended speed questions about each photo. On a five-point scale participants were asked to rate the road shown in each photo for driving difficulty (1 = "easy", 5 = "difficult"), overtaking opportunities (1 = "safe to overtake", 5 = "unsafe to overtake"), and overall safety (1 = "safe, e.g., parked", 5 = "unsafe, immediate danger"). These were followed by three open-ended questions; "what speed would you choose", "what is a safe speed for this road", and "what is the speed limit for this road". These questions were

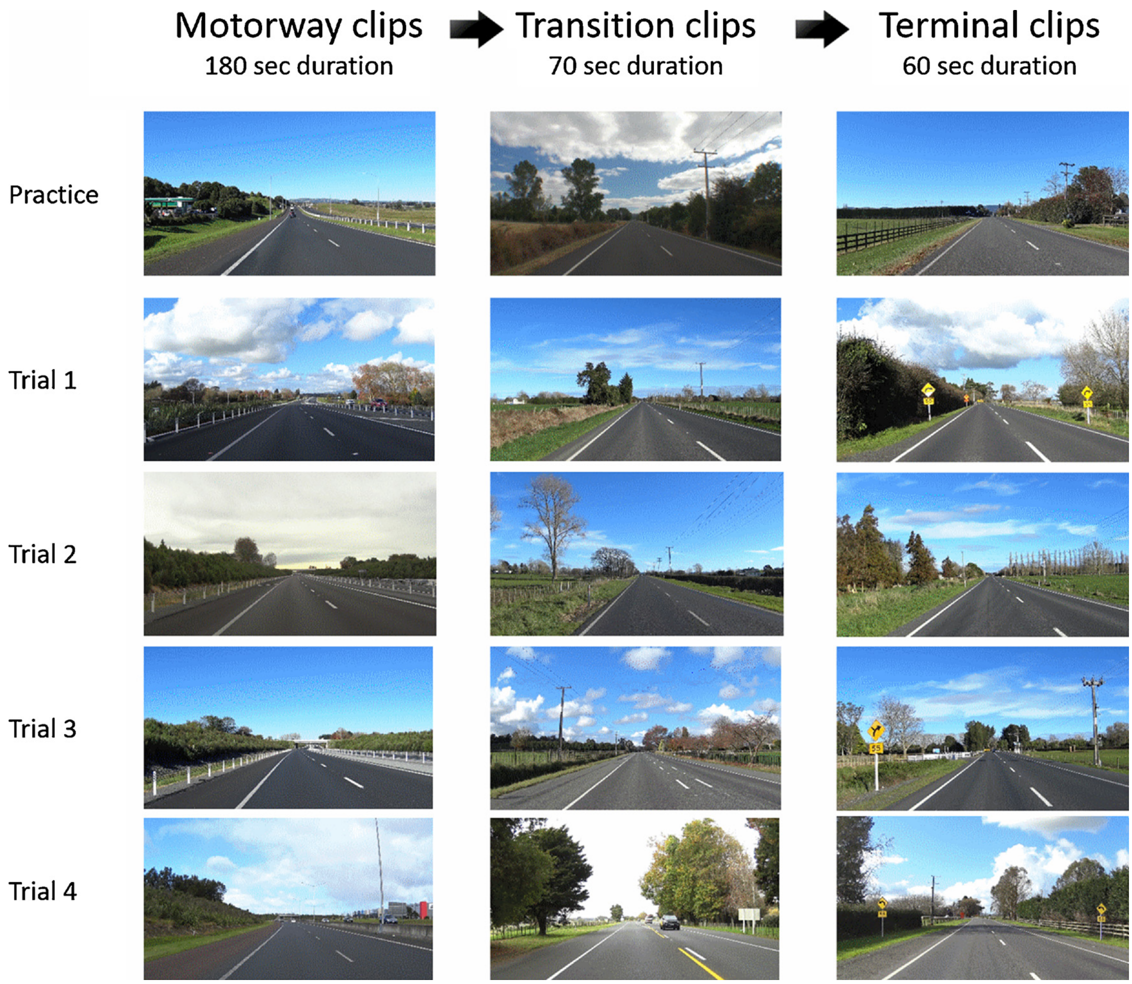

Fig. 1. The road videos presented to participants. The photo order was counterbalanced across trials 1, 3, and 4 and each of the terminal clips on those trials contained a 55 km/h curve located at 40–50 s.

adapted from previous studies (Charlton and Starkey, 2017a, 2017b). Following the open-ended questions the participants were asked several questions about their demographics and driving history.

2.3. Experimental design

The experiment was designed as a repeated-measures test with three levels of the independent variable, the three types of road marking depicted in the Transition clips (dashed white centre lines, wide centre lines, or complex centre lines). Participants completed four test trials,

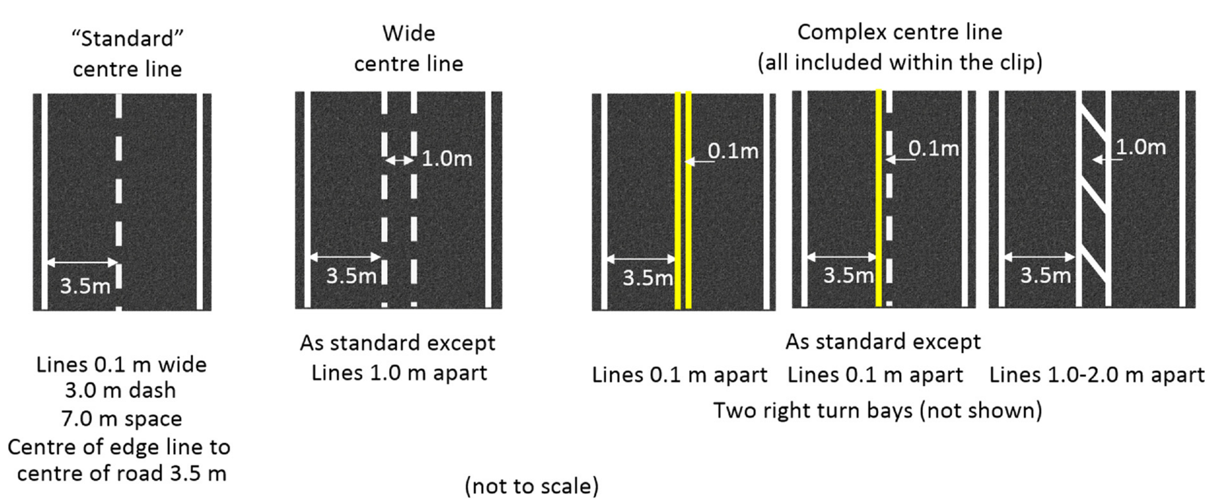

Fig. 2. A schematic of the three types of centre lines shown in the Transition video clips. The clip with the complex centre line changed through several configurations within the same clip. (Note the above drawings are indicative only, not to scale).

Table 1
A comparison of the mean speeds for the three Motorways, the Transitions (with dashed white, wide centre lines or complex markings) and the straight section of the Terminal clip following each of the Transition markings.

	Mean speed (km/h)	SD	Anova and effect size
Motorway			
1	102.46	3.66	
2	103.22	5.16	
3	104.20	7.14	$F(2,98) = 2.01$, $p = .139$, $\eta_p^2 = .039$
Transition			
Dashed white	98.81	7.27	
Wide centre line	97.92	9.11	
Complex	92.86[a]	10.22	$F(2,98) = 18.09$, $p < .001$, $\eta_p^2 = .270$
Terminal straight			
Dashed white transition	99.14	6.57	
Wide centre line transition	101.09	9.47	
Complex transition	99.21	6.83	$F(2,98) = 3.12$, $p = .066$, $\eta_p^2 = .060$

[a] significantly slower than dashed white (p = .016) and wide centre line (p = .007) η_p^2 = partial eta squared effect size.

preceded by a practice trial. Each test trial consisted of one of the 180 s motorway clips, followed by a 70 s Transition Clip, and then one of the Terminal clips (60 s). The different versions of each clip type were counterbalanced so that each Motorway clip was followed by each Transition clip equally often, and so on for the order of the Transition and Terminal clips. The exception to this counterbalancing was Trial 2, in which the clips used in each position remained constant for all participants. The Terminal clip for Trial 2 showed only a straight section of rural two-lane road with standard dashed white centre line, it did not contain a horizontal curve. This trial was used as a no hazard "foil" to prevent participants from assuming that the Terminal clip would always contain a hazardous curve. The order of presentation for each combination of Motorway, Transition, and Terminal clips was also counterbalanced so that order effects and learning effects did not have any systematic influence on the results. A variety of performance and rating measures were collected from the participants, but the dependent measures of greatest interest were the speed and magnitude of participants' reactions to the curves presented in the Terminal clips as described in Section 2.5 below.

2.4. Procedure

When participants arrived at the laboratory the purpose of the study was explained to them, any questions they had about the study were answered and they provided written informed consent. Participants were then given instructions on how to operate the driving simulator; to steer the car and to use the accelerator to speed up, and the brake to slow down to match the speed they would usually drive on these types of roads in their own car (as indicated by the speedometer). The participants then drove the practice trial (containing 3 clips) to familiarise themselves with the driving simulator task. Participants were allowed to repeat the practice drive if they wished to.

Next, the participants completed the four trials of simulated driving (see Fig. 1) which took approximately 35 min. At the end of the drive, participants were taken from the simulator to a desktop computer and asked to complete the questionnaire. At the end of the study participants were thanked and given a $20 gift voucher.

2.5. Data analysis

Initially we calculated the participants' speeds for the three Motorway clips, each road marking type during the Transition clips, and the post-transition speeds on the straight sections of the Terminal clips. In each of these cases the participants' speeds were measured at 1 s intervals and averaged across 10 s, from midway (sec 150–160 in the raw video footage) for the Motorway clips, near the end of the Transition clips (sec 50–60) and near the beginning of the Terminal clips (sec 10–20) before the curve warning sign came into view. These particular locations were chosen so that the participants had time to select their preferred speed for each clip, as all clips began playback at 100 km/h.

The results of primary interest were how well the different markings in the Transitions clips prepared the participants to react to the curve warning signs in the Terminal clips. To determine this, we measured the participants' Brake Reaction Times (BRTs) from the time the curve warning sign came into view (typically 5 s prior to the drivers reaching the sign) until the time the participants pressed the brake pedal to slow down (on 3 occasions participants already had the brake engaged as the sign came into view, and these three data points were discounted from analysis). We also measured the speed reduction participants achieved, subtracting their speed at the beginning of the curve, from their speed during the straight section of the same clip (sec 10–20, as described above) and calculated a percent reduction by dividing the result by their straight speed. Participants' curve speeds were measured at 1 s intervals beginning with the point at which they reached the curve and an average was calculated across the next 10 s of the curve, which was enough time for all participants to complete the curve.

Comparisons of the BRTs and speed differences associated with the three different Transition marking types were assessed with repeated-measures Anova, corrected according to the Greenhouse-Geisser formula where necessary. Post hoc pairwise comparisons of the three Transition markings used Bonferroni adjustments. The questionnaire ratings and speed answers were averaged for each of the four photograph categories and then statistically analysed with repeated-measures Anova for the speed-related ratings (in the same way as described for the BRT and speed data) and Friedman's test for the driving difficulty, overtaking and overall safety questions.

No reliable differences in performance due to participant age, years of driving experience, kilometres driven per week, or gender were identified in any of the statistical analyses.

3. Results

As described above, participants' speeds during the Motorway clips were compared as a consistency check. Their mean speeds over 10 s (approx. 280 m) was 103.29 km/h ($SD = 5.15$). As shown in Table 1, there were no significant differences in the speeds chosen between the three clips. In contrast, participants' speeds during the Transitions clips were significantly different, depending on which markings were present. As can be seen in Table 1, the participants' mean speeds were slowest during the complex centre line which were significantly lower than the dashed white centreline and wide centre line. Following the Transitions, participants' chose similar speeds for the early part of the Terminal clips (which were all dashed white centrelines), regardless of which type of markings they had just experienced during the Transitions. Comparison with Anova indicated that these differences were not reliably different when the Greenhouse-Geisser correction was applied (Table 1).

Of perhaps the greatest interest were the participants' BRTs when they reached the curve warning signs, these are shown in the top panel of Fig. 3. Repeated-measures Anova indicated that the difference in Terminal clip BRTs as a function of the preceding Transition clip was statistically reliable [$F(2,98) = 9.50$, $p < .001$, $\eta_p^2 = .162$]. As can be seen in the figure, the participants were quickest to brake to the sign (in the Terminal clip) when they had previously seen the dashed white centreline Transition clip; faster than after the complex centreline clip ($p < .001$) and the wide centreline ($p = .018$). BRTs to the sign were

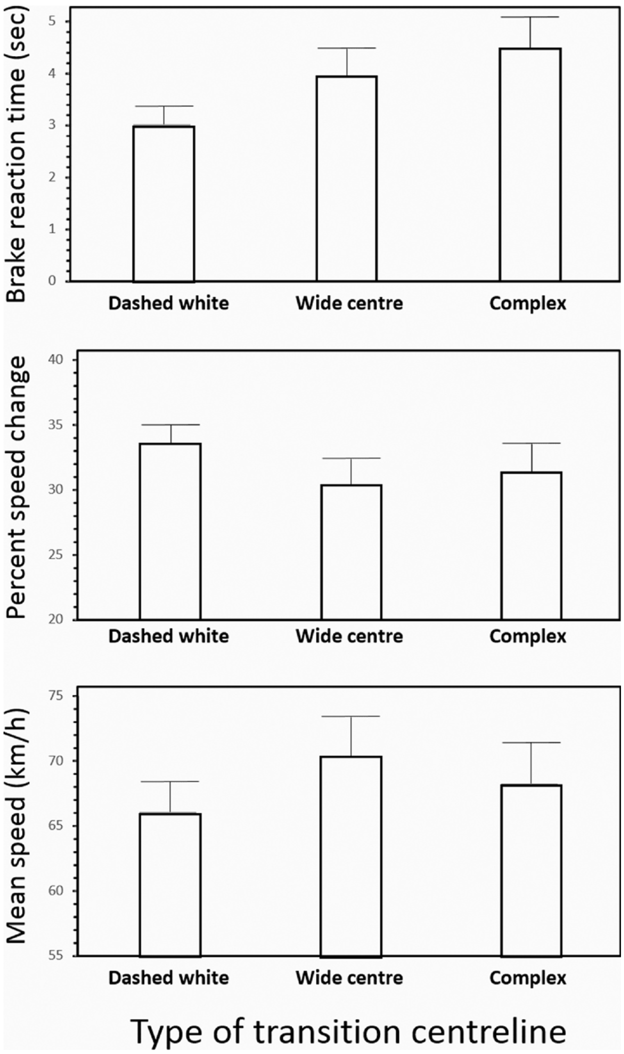

Fig. 3. Drivers' reactions to the horizontal curve as a function of the type of centreline marking in the transition as measured by: Top – mean brake reaction time to the curve warning sign (from the time the curve warning sign came into view until the time the participants pressed the brake pedal); Middle - mean percent speed reduction at the curve (speed on the straight minus speed at the beginning of the curve, dividing the result by speed on the straight); and Bottom - mean of participants' average speed through the curve clips. Vertical lines represent 95 percent confidence intervals.

not reliably different for wide centreline and complex centreline Transitions ($p = .507$).

Similarly, the dashed white centreline led to the largest percent reduction in speed at the curve as shown in the centre panel of Fig. 3. The overall difference between the groups was reliable [$F(2,98) = 4.07$, $p = .020$, $\eta_p^2 = .077$], the Bonferroni-adjusted comparisons showed that the mean percent speed reduction following the dashed white transition was significantly greater than the wide centreline transition ($p = .024$) but not than the complex centreline transition ($p = .172$), the wide centreline and complex centreline transitions were not significantly different ($p = .999$).

Finally, the dashed white centreline led to the lowest mean speed through the curve ($M = 66.05$ km/h, $SD = 9.08$) as compared to the complex centreline ($M = 68.24$, $SD = 10.12$) and the wide centreline ($M = 70.37$, $SD = 10.37$) (see lower panel of Fig. 3). Comparison with repeated-measures Anova indicated that the overall difference was significant [$F(2,98) = 5.99$, $p = .004$, $\eta_p^2 = .109$], with the Bonferroni-adjusted post hoc comparisons showing that the mean speed following the dashed white transition was significantly slower than the

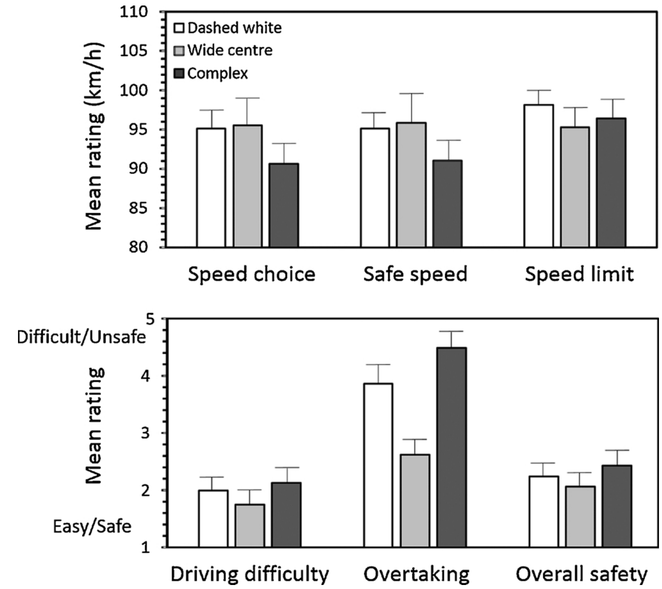

Fig. 4. The participants' ratings of the still photographs showing the three types of Transition centrelines. Vertical lines represent 95 percent confidence intervals.

wide centreline transition ($p = .004$) but not than the complex centreline transition ($p = .210$), the wide centreline and complex centreline transitions were not significantly different ($p = .312$).

Interestingly, the participants' speeds choice ratings of the still photos were nearly the same as the speeds they drove in the simulator. This highest speeds were chosen for motorways ($M = 102.23$, $SD = 7.79$), which were also rated as highest for safety ($M = 1.67$, $SD = 0.75$). The ratings for the other road markings are presented in Fig. 4. As shown in the top panel of Fig. 4, the participants said they would choose slower speeds for roads in the photos showing the complex centreline (flush median) as compared to the photos of roads with dashed white or wide centrelines, which is the same pattern of speeds observed during the Transition clips. The speed choice ratings were approximately 2.5 km/h slower than the speeds they drove in the simulation. A Repeated-measures Anova indicated that overall difference in speed choice ratings for the three centreline types was significant [$F(2,90) = 7.95$, $p = .001$, $\eta_p^2 = .150$], with post hoc comparisons showing speed choice for the complex centreline was rated significantly slower than either the dashed white ($p = .017$) or wide centreline ($p = .003$).

A nearly identical pattern of results was displayed for the participants' ratings of what they thought was a safe speed for the roads shown in the photos. There was an statistically reliable overall difference between the three centrelines [$F(2,90) = 6.87$, $p = .002$, $\eta_p^2 = .132$], with post hoc comparisons showing the rated safe speed for the complex centreline was rated significantly slower than either the dashed white ($p = .016$) or wide centreline transition ($p = .007$). Nearly all the participants' rated the speed limit for the roads shown in these photos the same, 100 km/h, with no statistically reliable difference between the three types [$F(2,90) = 2.66$, $p = .076$, $\eta_p^2 = .056$]. \

The participants' ratings of driving difficulty (see lower panel of Fig. 4) indicated that the photos with wide centrelines were perceived as easier to drive than the complex centre lines as indicated by a significant overall Friedman's result [$X^2(2) = 16.11$, $p < .001$], and significant post hoc test ($p = .004$). The difference in difficulty ratings between the dashed white and wide centrelines approached statistical significance ($p = .065$). The photos of roads with wide centrelines were also rated as safest for overtaking, with a significant overall Friedman's test result [$X^2(2) = 50.27$, $p < .001$], and post hoc comparisons to roads with dashed white ($p = .001$) and complex centrelines ($p <$

.001). In addition, the photos of roads with dashed white centrelines were rated as safer to overtake than the complex centrelines / flush medians ($p = .017$). Finally, there was a significant difference in the ratings of overall safety [$X^2(2) = 9.81, p = .007$] with the safest ratings once again associated with the photos of wide centrelines and post hoc comparisons indicating that these markings were rated as significantly safer compared to those with complex centrelines ($p = .037$).

4. Discussion

The immediate goal of the experiment was to identify which type of road marking best prepared drivers to slow down for horizontal curves after they had become accustomed to traveling at high speed on a straight, divided motorway. This was of interest for the practical reason of increasing the safety of moving from roads with a high level of service and safety provisions to roads of lower levels of service and safety. It was also of interest from the theoretical perspective of determining the road characteristics that result in drivers' shift in expectations regarding the road conditions ahead.

As regards the first goal it was evident that for the roads used in the experiment, the dashed white centreline Transition produced the best outcome for participants' responses to the horizontal curves; faster reaction times, greater reductions in speed, and slower speeds through the curves. This is in spite of the fact that during the transition, participants chose the lowest speeds for the complex centreline, in the simulator and in the photo ratings. The complex centreline, containing a mixture of yellow no passing lines, flush medians, and turn bays, was apparently conspicuous enough to result in a momentary reduction in speed, but not enough to produce a sustained mode change and prepare drivers to rapidly respond to a hazard. The influence of perceptions of risk on drivers' speed choice generally has been investigated previously (Benda and Hoyos, 1983; Kanellaidis et al., 2000; Taylor, 1964) and the association between no overtaking lines, perceptions of risk, and speed reductions has been demonstrated specifically (Charlton and Starkey, 2016). The present results suggest, however, that this effect exists only as long as the as the lines are present and does not produce generalised or long-lasting caution, there being no evidence of continued speed reduction after the transition or preparedness for reacting to hazards.

Instead, the switch in expectations from motorway to country road may be a more gradual and subtle change. In the present experiment, this change appeared to be achieved best when a dashed white centreline in Transition was followed by dashed white centreline in the Terminal clips. This suggests that a more sustained exposure to the changed road environment may be needed to effect a change in expectation, and the complex centreline and wide centreline treatments did not contribute to, and in fact delayed, the participants' change in expectations to one appropriate to a rural country road.

With regard to the wide centreline treatment, the results of the photo rating task indicated that participants rated these roads as safest overall, safest for overtaking, and as easiest to drive. Further, in the simulator the participants' wide centreline speeds during transition were equivalent to their dashed white centreline speeds, suggesting that wide centrelines do not convey to drivers the high risk of many of New Zealand's rural roads. Perhaps even more importantly, the wide centre lines led to the lowest percent speed reduction in advance of the curve and the highest speed around the curve, indicating that these lines are not effective in promoting appropriate expectations and preparing drivers for hazards.

Taken together, the findings of the experiment generally support the idea that drivers do have a mental representation or schema for familiar types of roads, in this case typical NZ rural roads. How a road looks to the driver seems to not only dictate their choice of speed at that moment, but also appears to influence their expectations of, and ability to react to, future hazards. This supports previous work showing the importance of predictable road markings in conveying accurate information to the driver about the type of road they are on (Aarts and Davidse, 2007, 2008; Stelling-Konczak et al., 2011).

What we cannot resolve from the present experiment, however, is whether the switch from one driving mode or attentional set to another results from a conscious determination by the driver that the character of the road has changed, or whether this switch occurs at an unconscious level and whether it occurs gradually or all at once. In the present experiment, we do not know when the mode switch resulting from the dashed white centrelines occurred, or whether this switch was a conscious decision by the participants. What we can say is that the unusual and complex centrelines didn't prepare participants for the subsequent curve, suggesting that they were not effective warning signals for typical rural road hazards of that type.

To be sure, the methods used in the present experiment have some limitations when we try to draw generalisations to actual road environments. In particular, although the duration of the clips in our experiment was near the upper limit of what we could expect volunteer participants in the laboratory to endure, it was far from the length of exposure that one would experience in a trip on the road. With rural roads of this type it is not possible to vary the overall width of the paved surface independently of the road markings. In other words, roads with wide or complex centrelines were necessarily wider than the roads with dashed white centrelines, which may have contributed to the results obtained (but interestingly there was no evidence of this during the Transition clips). Further, in the driving scenarios for this experiments we deliberately eliminated scenes with heavy traffic, particularly heading traffic. It is possible that the results might be different under other traffic conditions. It is also possible of course that the participants would not be equally prepared for other sorts of road and traffic hazards; we elected to use horizontal curves as one indication of a hazard common to two-star roads but absent from the five-star motorways.

As shown in Table 1, the participants' speed choices obtained in the present study were, on average, very close to the speed limit, slightly above for the motorway and slightly below for the two-star rural roads. Drivers' speed choices are influenced by a large number of factors and mean speeds can be quite different to posted speed limits depending on the characteristics of the road, and when the speeds are measured (Ahie et al., 2015; Elvik, 2010; Goldenbeld and van Schagen, 2007). We did not attempt to investigate the effect of transitions across anything like the full range of these factors in the present study. Instead, we chose a constrained set of roads so that, to the degree possible, only the road markings during the transition clips varied, and we could give drivers a little longer exposure to each road clip. Within the experiment it was encouraging to note that the speed choice ratings showed good agreement with the speeds produced in the simulator, suggesting that the pattern of participants' choices were somewhat reliable and offering potential value for using this mixture of methods in harmony in future experiments.

This study is the first, so far as we know, to evaluate the degree to which road markings can be used to influence subsequent behaviour, specifically drivers' preparation to react to a hazard. While further work will be required to see whether the effect will extend to other sorts of rural road hazards (e.g. traffic at intersections) there are some clear recommendations that can be made. First and foremost, the look of a road needs to convey a clear and unambiguous message to drivers. The transition to a two-star rural road is best achieved by making the road look like a typical two-star road as soon as possible. Other sorts of markings intended to be alert drivers or serve as some sort of transitional buffer do not provide a predictable message about the type of road that lies ahead. To be sure, improving the safety of our two-star rural roads should be undertaken, but the appearance of those improvements should not mislead, confuse, or inflate the perceived safety of the road.

Acknowledgments

The work was funded by the NX2 Motorway Consortium and the authors would like to acknowledge the consortium members, and NZ Transport Agency staff who served as a steering group for this project, as well as all the participants, research assistants, and technical support staff who worked with us on this project.

References

Aarts, L., Davidse, R., 2007. The recognisability of rural roads in the Netherlands. In Proceedings of the European Transport Conference. Leiden.
Aarts, L.T., Davidse, R.J., 2008. Behavioural effects of predictable rural road layout: a driving simulator study. Adv. Transp. Stud. 14, 25–34.
Agent, K.R., 1980. Transverse pavement markings for speed control and accident reduction. Transp. Res. Rec. 773, 11–14.
Ahie, L.M., Charlton, S.G., Starkey, N.J., 2015. The role of preference in speed choice. Transp. Res. Part F Traffic Psychol. Behav. 30, 66–73.
Benda, H.V., Hoyos, C.G., 1983. Estimating hazards in traffic situations. Accid. Anal. Prev. 15 (1), 1–9.
Borowsky, A., Shinar, D., Parmet, Y., 2008. Sign location, sign recognition, and driver expectancies. Transp. Res. Part F Traffic Psychol. Behav. 11, 459–465.
Borowsky, A., Oron-Gilad, T., Parmet, Y., 2009. Age and skill differences in classifying hazardous traffic scenes. Transp. Res. Part F Traffic Psychol. Behav. 12, 277–287.
Borowsky, A., Shinar, D., Oron-Gilad, T., 2010. Age, skill, and hazard perception in driving. Accid. Anal. Prev. 42, 1240–1249.
Briggs, G.F., Hole, G.J., Turner, J.A., 2018. The impact of attentional set and situation awareness on dual tasking driving performance. Transp. Res. Part F Traffic Psychol. Behav. 57, 36–47.
Charlton, S.G., 2007. The role of attention in horizontal curves: a comparison of advance warning, delineation, and road marking treatments. Accid. Anal. Prev. 39, 873–885.
Charlton, S.G., Starkey, N.J., 2013. Driving on familiar roads: automaticity and inattention blindness. Transp. Res. Part F Traffic Psychol. Behav. 19, 121–133.
Charlton, S.G., Starkey, N.J., 2016. Risk in our midst: centrelines, perceived risk, and speed choice. Accid. Anal. Prev. 92, 192–201.
Charlton, S.G., Starkey, N.J., 2017a. Drivers' mental representations of familiar rural roads. J. Environ. Psychol. 50, 3–8.
Charlton, S.G., Starkey, N.J., 2017b. Driving on urban roads: how we come to expect the 'correct' speed. Accid. Anal. Prev. 108, 251–260.
Charlton, S.G., Mackie, H.W., Baas, P.H., Hay, K., Menezes, M., Dixon, C., 2010. Using endemic road features to create self-explaining roads and reduce vehicle speeds. Accid. Anal. Prev. 42, 1989–1998.
Charlton, S.G., Starkey, N.J., Perrone, J.A., Isler, R.B., 2014. What's the risk? A comparison of actual and perceived driving risk. Transp. Res. Part F Traffic Psychol. Behav. 25, 50–64.
Denton, G.G., 1980. The influence of visual pattern on perceived speed. Perception 9, 393–402.
Elliot, M.A., McColl, V.A., Kennedy, J.V., 2003. Road Design Measures to Reduce Drivers' Speed Via' psychological' Processes: a Literature Review. Report Number TRL564. Transport Research Laboratory, Crowthorne, Berkshire, UK.
Elvik, R., 2010. A restatement of the case for speed limits. Transp. Policy 17, 196–204.
Elvik, R., 2013. A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims. Accid. Anal. Prev. 50, 854–860.
Fildes, B.N., Jarvis, J., 1994. Perceptual Countermeasures: Literature Review. Report CR4/94. Federal Office of Road Safety, Canberra, Australia.
Godley, S., Fildes, B., Triggs, T., Brown, L., 1999. Perceptual Countermeasures: Experimental Research. (Road Safety Research Report CR 182.) Clay. Monash University Accident Research Centre, Victoria.
Goldenbeld, C., van Schagen, I., 2007. The credibility of speed limits on 80 km/h rural roads: the effects of road and person(ality) characteristics. Accid. Anal. Prev. 39, 1121–1130.
Gundy, C.M., 1994. Cognitive Organization of Roadway Scenes: An Empirical Study. R-94-86. Leidschendam. Institute for Road Safety Research SWOV, The Netherlands.
Harms, I.M., Brookhuis, K.A., 2016. Dynamic traffic management on a familiar road: Failing to detect changes in variable speed limits. Transp. Res. Part F Traffic Psychol. Behav. 38, 37–46.
Kanellaidis, G., Zervas, A., Karagioules, V., 2000. Drivers' risk perception of road design elements. Transp. Hum. Factors 2, 39–48.
Koorey, G.F., Tate, F.N., Cenek, P.D., Page, S.J., 2001. Use of Curve Advisory Speed Signs in New Zealand. In Road Safety Research, Policing and Education Conference, 2001. Australasian College of Road Safety, Melbourne, Australia.
Martens, M.H., Fox, M.R.J., 2007. Do familiarity and expectations change perception? Drivers' glances and response to changes. Transp. Res. Part F Traffic Psychol. Behav. 10, 476–492.
Martindale, A., Urlich, C., 2010. Effectiveness of transverse road markings on reducing vehicle speeds. NZ Transport Agency Research Report 423. NZ Transport Agency, Wellington.
Montella, A., Aria, M., D'Ambrosio, A., Galante, F., Mauriello, F., Pernetti, M., 2011. Simulator evaluation of drivers' speed, deceleration and lateral position at rural intersections in relation to different perceptual cues. Accid. Anal. Prev. 43, 2072–2084.
NZTA, 2014. State Highway Activity Management Plan. New Zealand Transport Agency, Wellington, NZ, pp. 2015–2018.
Sarter, N.B., Woods, D.D., 1995. How in the world did we ever get into that mode? Mode error and awareness in supervisory control. Hum. Factors 37 (1), 5–19.
Shinar, D., 2017. Traffic Safety and Human Behavior. Bingley. Emerald Publishing Limited, England.
Stelling-Konczak, A., Aarts, L., Duivenvoorden, K., Goldenbeld, C., 2011. Supporting drivers in forming correct expectations about transitions between rural road categories. Accid. Anal. Prev. 43, 101–111.
Taylor, D.H., 1964. Drivers' galvanic skin response and the risk of accident. Ergonomics 7, 439–451.
Theewes, J., Godthelp, H., 1992. Self-explaining roads. Saf. Sci. 19, 217–225.
Waibl, G., Tate, F., Brodie, C., 2012. The development of a proactive road safety assessment tool – KiwiRAP. Proceedings of Australasian Road Safety Research, Policing and Education Conference 2012, 4-6 October 2012 1–11.
Weller, G., Schlag, B., Friedel, T., Rammin, C., 2008. Behaviourally relevant road categorisation: a step towards self-explaining rural roads. Accid. Anal. Prev. 40, 1581–1588.
Young, A.H., Mackenzie, A.K., Davies, R.L., Crundall, D., 2017. Familiarity breeds contempt for the road ahead: the real-world effects of route repetition on visual attention in an expert driver. Transp. Res. Part F Traffic Psychol. Behav. 57, 4–9.