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The possible safety benefits of enhanced road markings: A driving simulator evaluation

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Abstract

A comparison of the relative effectiveness under simulated wet night driving conditions of an enhanced road-marking system with commonly used highway markings was undertaken. Participants completed drives with both types of markings. A secondary mental arithmetic task was also employed in half of the conditions. Both objective and subjective data were collected. The results indicated that participants were better able to maintain lane position and speed with the enhanced markings than with the standard markings. A similar pattern was found for the subjective measures: workload was rated as lower for the enhanced markings; likewise, subjects reported the drives as being easier and were more confident in being able to drive safely when the roads displayed the enhanced markings. These findings point to a potential safety benefit from greater use of such enhanced roadway markings.

Keywords: Road markings; Line markings; Driver behaviour; Simulation

1. Introduction

The majority of traffic fatalities in industrialised countries such as the United States and Australia occur at night, with the death rate estimated at between three and four times higher at night than during the day when adjusted for distance travelled (Owens, 2003). Improving night-time visibility can be a major factor in reducing accidents; moreover, improving visibility for drivers on wet nights has long been identified as requiring more attention (Boyce, 1981).

The importance of providing edgelines and centrelines has been demonstrated by studies that found that the presence of such lines reduced all accidents by 20% (Miller, 1992) and single vehicle accidents by 34% (Moses, 1986). One problem on wet nights is that the visibility of edgelines and centrelines is reduced because water lying on the line diminishes the amount of light reflected. Therefore, edgelines and centrelines with high retro-reflectivity when wet might further improve safety.

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The majority of roads in industrialised countries have markings painted onto them to delineate the edge and centre of the roadway. For example, in the Australian state of Victoria the standards for rural road delineation treatments have a typical centreline pattern of 3 m stripe and a 9 m gap, and a line width of 100 mm. The edgeline is unbroken and is 100 mm wide on most 'B' and 'C' class roads (this includes some state highways, tourists roads and roads connecting rural towns) (VicRoads, 2001, following Australian standards 1742, 2009 and 4049). Such standards generally specify the physical sizes, locations and permitted types of materials for the markings but give less advice concerning precisely when such different marking materials should be used. Thus, the choice of the exact material to be used is largely the decision of highway engineers in each state road authority.

1.1. Behavioural effects of edge and centrelines

Edgelines have been shown to reduce accidents, but they have not been found to reduce vehicle speed (Fildes, Fletcher, & Corrigan, 1987; Willis, Scott, & Barnes, 1984). In some cases the presence of edgelines has even been shown to increase driver speed (Johnston, 1983; Ranney & Gawron, 1986) possibly because edgelines increase driver confidence. Ranney and Gawron (1986) found that although drivers drove at higher speeds, fewer drivers exceeded the speed limit. They suggested that higher speeds were associated with lower workload, leading to faster but more controlled driving (such as less instances of speeding).

The other main influence of edgelines on driver behaviour is in lateral control. Unsurprisingly, increased lateral control is linked to reduced accident rates (Godley, 1999). In a simulator study of the effect of edgelines, it was found that low visibility edgelines were associated with more lane-keeping errors; higher visibility of the edgelines increased driving speeds and decreased lane-keeping errors (McKnight, McKnight, & Tippetts, 1998).

The addition of a centreline has been found to influence vehicle placement in the road whereby vehicles travelled closer to the centre of the road and crossed over onto the other side of the road less often (Triggs & Wisdom, 1979). The addition of a centreline has not been found to affect driving speeds (Triggs & Wisdom, 1979; Yagar & van Aerde, 1983).

1.2. Perceptual guidance

The visual guidance function of road markings is particularly important when visibility is low and other environmental cues cannot be used (Godley, 1999). Road markings should provide continuous information about the location of the road centre and edges. Because markings are generally perceived in peripheral vision, this information is therefore received without drivers shifting their eyes away from the road (Schnell, Aktan, Ohme, & Hogsett, 2003; Zwahlen & Schnell, 1998). Road markings often therefore provide a continuous perceptual link between the driver and the environment.

1.3. Factors affecting visibility at night

1.3.1. Glare

One factor that affects highway visibility is glare from the headlights of oncoming vehicles. Theeuwes, Alferdinck, and Perel (2002) found that even if glare is not sufficient to affect visual discrimination it can nonetheless affect driver behaviour. Drivers drove at a lower speed when there was a source of glare, and this was accentuated when the road conditions were winding and dark. Drivers appeared to be compensating for the difficulties of lane-keeping when visibility was low by driving more slowly.

1.3.2. Vision, markings and the effects of age

It is well known that many visual abilities are affected by age. Regarding markings, retro-reflectivity requirements for older drivers have been examined by many researchers over the past decade, or example Zwahlen and Schnell (1998), Graham, Harrold, and King (1996), Schnell et al. (2003), and Parker and Meja (2003). Zwahlen and Schnell (1998) assessed end-detection distances (i.e. visibility distances at which subjects reported seeing the end of the marking line) with different types of pavement markings and different illumination conditions with younger and older drivers. End-detection distances were 55% higher for the younger age group. Although both retro-reflectivity and headlamp illumination influenced end-detection distance, retro-reflectivity had more of an effect. This indicates that improving night-time visibility of edge and centrelines may not always be achieved purely by providing greater illumination of the roadway. The physical properties of the markings themselves are also of importance in determining visibility, for drivers of all ages.

1.3.3. Types of roadway markings

For nearly fifty years, glass beads embedded in painted markings have been used in highway delineation. The glass beads reflect light from the headlights back to its source, thus providing reflected light to guide the driver (Kalchbrenner, 1989; Parker & Meja, 2003). However, with the standard road markings used in Australia there is usually a major loss of retro-reflectivity in the rain. This is mainly due to the small size (<1 mm diameter) of the glass beads. Larger glass beads (>1 mm diameter) have been shown in both laboratory tests and field studies to be more retro-reflective and to provide more effective wet night visibility (Kalchbrenner, 1989).

Building on the above, it was hypothesised that improved marking visibility might contribute to improving driving performance and reducing driving errors at night. In addition, highly visible markings might enable drivers experiencing a higher workload (due to, for example, talking to a passenger) to drive more safely at night.

Therefore, the general aim of this research was to evaluate the effect under simulated wet night driving conditions of a highway delineation line technology using larger glass beads (termed ‘enhanced’ marking here) compared to traditional highway markings. The effects on safe driving performance for both types of markings was undertaken when there was simulated oncoming traffic and glaring headlights in an unlit rural road. Previous studies by other researchers examining the relative performance of different types of markings for wet weather night driving have focused largely on assessment of end-detection distances or accident rates. This present work aims to add to the literature by investigating behavioural performance in a driving simulator in which a large number of driver behavioural and subjective measures were obtained for the two types of markings.

2. Pre experimental development and evaluation

The aim of the research was to evaluate in a driving simulator the effect on driver behaviour of two types of road markings with different amounts of retro-reflectivity. However, retro-reflectivity cannot be directly created or measured in a driving simulator. Considerable effort was therefore expended to maximise the realism of the markings by other means. As with most simulator studies, bridging the fidelity gap between created simulator scenes and real roads was vital for any obtained results to be meaningful and valid. To undertake this, a series of evaluations and re-designs were performed. These are described below.

The simulated markings were developed by viewing a test road specially marked with both types of lines. At one point of the test road they were adjacent to each other, at another point they were marked sequentially. Viewing was undertaken at night under wet conditions; static and dynamic digital images (Sony digital video model TRV8E with CCD chip) and measurements of visibility distances for both the adjacent and sequential markings were recorded and compared. Following this, the exact distances for which each type of marking was visible when illuminated with high beam[2] car headlights was re-created by the same observers in the simulator under the precise experimental set-up.

2.1. Expert advisory panel

Three road-marking experts from three state road and traffic authorities around Australia served on an expert advisory panel. The purpose of the panel was to give objective opinions and feedback about the accuracy and realism of the markings created in the simulator.

[2] The driving scenarios used were based on rural night-time scenes. Drivers in similar real world environments would typically use high beam headlights in such situations, hence visibility distances with high beam, rather than low beam, headlights were used.

The first expert advisory panel meeting involved the three road-marking experts and members of the research team. Simulator scenarios of wet night driving conditions containing the two types of road markings were driven in by each of the panel members. Panel comments, feedback and improvement suggestions were recorded.

The second expert advisory panel meeting took place after the changes from the first panel session were implemented. It involved the same three road-marking experts and research team members. Again, each of the panel members drove through the night-time driving scenes containing the two modified marking types, including on bends. The team gave final approval regarding the realism and accuracy of the markings and scenes created. Their remaining comments were incorporated into the final versions of the simulator scenes before the experimental trials took place.

3. Method

3.1. Equipment

The study was undertaken in the Monash University Accident Research Centre's driving simulator located in Melbourne, Australia. It comprises a full car (for this study, a 1994 model Ford Falcon), two silicon graphics computers, a motion platform, a 3D audio system and advanced video projectors displaying images on a curved screen in front of the driver (with a lateral viewing angle of 180° forward).

3.2. Participants

In total, 25 participants completed the study. All drivers had a full Australian car licence, and had been driving for over one year. There were 13 drivers aged less than 30 years (mean age 23.6 years, range 19–29,) and 12 drivers aged over 55 years (mean age 61.1 years, range 56–72). All participants were active drivers, having driven a vehicle at night recently. These general age ranges have previously been successfully used in related studies with the driving simulator (for example, Horberry, Anderson, Regan, Triggs & Brown, in press). Each participant was paid for his or her participation. All participants reported having normal, or corrected-to-normal, vision.

3.3. Design and driving scenarios

The study was a mixed factorial design with each participant completing all conditions in the experiment. The within-subjects factors were type of road markings (standard and enhanced) and additional task (present or absent). Two age groups of participants (younger and older) were tested. Each subject participated in the following four experimental conditions:

1. Driving with the standard markings with no additional task.
2. Driving with the standard markings whilst undertaking the additional task.
3. Driving with the enhanced markings with no additional task.
4. Driving with the enhanced markings whilst undertaking the additional task.

The additional task used was mental arithmetic; this task has previously been used successfully in similar studies investigating driver workload using the simulator facility (for example, Horberry et al., in press). Participants wore headphones and responded verbally via a microphone. They were presented with a two-digit number, such as 47. They were required to mentally separate this number into 4 and 7, and then give the absolute difference between the two numbers (i.e. 3). The task was forced-paced with a new number being presented every 2 s. Participant's performance in the mental arithmetic tasks was not explicitly measured.

The driving scenarios were approximately 6 km in length. The road was a simulated rural scene with no street lighting. The gradient was level, but several curves were contained within the drive. The speed limit was 100 km/h and signs were placed at regular intervals in all the scenes. The road was single carriageway in either direction with each lane being 3.2 m wide. The total road width was therefore 6.4 m. The markings were 100 mm wide. The edgelines were unbroken, but the centreline was broken, with a 3 m stripe followed by a 9 m gap (following VicRoads, 2001).

Oncoming traffic was displayed in all conditions. However, because the simulator used a series of projectors to display the visual images to participants, an additional technique was devised to simulate an oncoming vehicle's headlights. To achieve this, a purpose built light source, comprising two LEDs, was mounted on the bonnet of the simulator vehicle and directed towards the driver. They were operated by the researcher pressing a trigger, and shone for a period of 5 s. The intensity of the light level simulated the increasing brightness levels of oncoming vehicles. The operation of the LEDs was linked to the simulator so that they were triggered at the same pre-defined points in all four experimental conditions.

In order to simulate the reflections created by water on the windscreen and in the environment, plastic cling wrap was placed on the windscreen of the simulator vehicle. This had the effect of making the view of the driving scene slightly hazy, as would be experienced when driving in the rain (however, as mentioned earlier, the visibility distances were exactly matched to the measurements obtained during the field measurements at the test road).

3.4. Performance measures

Both objective and subjective measures of driver performance were obtained. The objective measures included driving 'errors' such as variations in roadway position (deviation in road position and crossings of edge and centrelines) and variations in vehicle speed (deviations of speed from the posted speed limit). The subjective measures gauged participants' experiences of the different driving conditions. They included workload (by means of the NASA–TLX), participant confidence in their ability to drive safely and perceived difficulty of the different drives.

3.5. Procedure

Each participant was tested individually. After completing a questionnaire of basic information, such as age, they were introduced to the driving simulator and shown the functions of the vehicle. They then took part in a practice trial for approximately 5 min to familiarise them with the simulator vehicle and experimental tasks.

Following this, they undertook the four experimental drives. Presentation order was counterbalanced between-subjects. The general instructions for the drives were as follows:

> Drive as you normally would, and obey the road rules. Drive as closely as possible to the indicated speed limit. Continue driving until you are instructed to stop.

After each drive, subjects completed the NASA–TLX questionnaire and associated material. In total, the experiment usually lasted less than 1 h per subject.

4. Results

The objective simulator data are presented first. The lost data rate in the simulator was up to 20%.[3] Following this, the subjective data are reported.

4.1. Objective simulator data

For the results below the values were averaged across all subjects. Data were recorded for approximately 5 km in each drive, starting at a pre-defined point 1 km into each drive.

[3] Mainly due to technical difficulties with simulator data recording. As the experimental design was between-subjects, where data were lost for one subject in any drive none of that subject's data were analysed.

Table 1
Mean speed for the four conditions

	Standard markings (km/h)	Enhanced markings (km/h)
No additional task	88.66	91.86
With an additional task	86.98	92.50
Average of the two tasks	87.82	92.18

Table 2
Mean standard deviation of speed for the four conditions

	Standard markings (km/h)	Enhanced markings (km/h)
No additional task	7.35	5.49
With an additional task	8.32	6.03
Average of the two tasks	7.84	5.76

Table 3
Standard deviation of lateral road position for the four conditions

	Standard markings (m)	Enhanced markings (m)
No additional task	0.337	0.292
With an additional task	0.326	0.288
Average of the two tasks	0.331	0.290

4.1.1. Mean speed

As mentioned earlier in this paper, drivers were asked to drive as closely as possible to 100 km/h. Speeds that differed markedly from 100 km/h therefore indicated lower performance. The mean results for the four conditions are shown below (see Table 1).

A Repeated Measures 2×2 general linear model (GLM) comprising two marking types (standard and enhanced), and two task types (with and without the mental arithmetic task) was applied to these data. The effects of age were included in the model as a between-subjects factor.

The GLM showed a significant effect for the type of marking ($\mathrm{df} = 1, 18$, $F = 11.85$, $P = 0.004$). Means indicated that participants drove significantly closer to the target speed with enhanced markings compared to the standard markings. The presence or absence of the mental arithmetic task did not significantly affect speed and there were no differences due to age.

4.1.2. Standard deviation of speed

This measure examined how constant was a participant's speed.[4] With this measure, less deviation represented better task performance. The mean results for the four conditions are shown below (see Table 2).

A GLM showed a significant effect for the type of marking ($\mathrm{df} = 1, 18$, $F = 8.051$, $P = 0.012$), indicating that participants drove at a more constant speed in the two drives with the enhanced markings compared to those with standard markings. The presence or absence of the additional task had no significant effect on standard deviation of speed. Likewise, no differences were found due to age.

4.1.3. Standard deviation of lateral road position

This measure examined how much a driver was able to maintain a constant road position, with less deviation representing better task performance. The mean results are shown below (see Table 3).

A GLM showed a significant main effect for the type of marking ($\mathrm{df} = 1, 18$, $F = 5.756$, $P = 0.03$). Standard deviations in road position were significantly lower for the enhanced marking conditions, indicating that drivers held a more constant roadway position in the two drives with enhanced markings compared to the two

[4] As with all the objective data, this was recorded 30 times per second in the simulator.

Table 4
The number of crossings per drive over the centre or left edgeline

	Centreline		Left edgeline	
	Standard markings	Enhanced markings	Standard markings	Enhanced markings
No additional task	5.37	2.37	3.37	2.95
With an additional task	5.47	2.79	3.37	2.63
Average of the two tasks	5.42	2.58	3.37	2.79

Table 5
The total time (in seconds) that participants crossed the centre and left edgeline per drive

	Centreline		Left edgeline	
	Standard markings	Enhanced markings	Standard markings	Enhanced markings
No additional task	14.43	5.28	17.18	11.32
With an additional task	12.52	6.92	14.88	12.23
Average of the two tasks	13.48	6.10	16.03	11.78

drives with the standard markings. Again, surprisingly, no significant differences were found between drives with and without the mental arithmetic task. Moreover, no differences were found due to age.

4.1.4. Crossings of edge and centrelines

This measure examined whether a participant drove part of their vehicle over either the left edge[5] or the centreline in the road. Table 4 shows the number of times participants drove over the edge/centrelines, and Table 5 shows the total length of time participants were over these lines (i.e. part of their vehicle was outside the correct lane in the roadway) during each of the drives.

In terms of safe driving performance, of course, not driving over the edge/centrelines, and having no time when part of the vehicle was over these lines, is preferable. As such, lower numbers in the following results represented better task performance.

For the number of crossings of the centrelines, a GLM showed a significant main effect for the type of marking ($df = 1,18$, $F = 10.155$, $P = 0.05$). The number of centreline crossings was significantly lower for the enhanced marking conditions compared to the standard marking conditions. No significant differences were found between drives with and without the mental arithmetic task. Moreover, no differences were found due to age.

A similar picture was found for the left edgelines. A GLM showed a significant main effect for the type of marking ($df = 1,18$, $F = 5.299$, $P = 0.03$). The number of left edgeline crossings was significantly lower for the enhanced marking conditions compared to the standard marking conditions. Again, no significant differences were found between drives with and without the mental arithmetic task. Likewise, no differences were found due to age.

For the total time that participants crossed either the centre and left edgeline per drive, a GLM surprisingly showed no significant main effects for the type of marking nor type of task. In addition, no differences were found due to age. This lack of significant results can partly be explained by the high degree of variance between-subjects in terms of the amount of time spent outside lane.

However, averaging the total time outside the centre and left edgelines, and the two tasks, gives an average total time spent outside lane of 8.94 s for the enhanced markings and 14.75 s for the standard marking conditions. A paired samples *T*-Test showed a statistically significant difference ($t = 2.737$, $df = 18$, $P = 0.014$) here.

4.2. Subjective measures: workload and other data

Participants completed a NASA–TLX questionnaire after each drive. The survey also asked two additional questions; participants rated on a 20-point scale:

[5] Driving is on the left hand side of the road in Australia.

1. How confident they were in being able to drive safely in their last drive?
2. How easy they thought the last drive was?

In this section the overall workload results, the workload sub-scale results and the results about confidence/easiness are described.

As with most of the objective data, a GLM was used. The design was a Repeated Measures 2×2 GLM [two marking types-standard and enhanced, and two task types-no other task and an additional mental arithmetic task]. The effects of age were included in the model as a between-subjects factor.

4.2.1. Overall workload scores

For this experiment the overall NASA–TLX workload score was defined as the average of the six workload sub-scales. Workload was scored on a scale that ranged from 0–20. The results are shown in Fig. 1 below.

A GLM showed a significant effect for the type of marking (df = 1,23 $F = 23.53$, $P = 0.000$). Participants rated workload lower in the two drives which showed the enhanced markings than for the two drives that showed standard markings. Additionally, perceived workload was lower when no additional task was employed. The GLM showed a significant effect of type of task used (i.e. no task or an additional task) (df = 1,23, $F = 71.90$, $P = 0.000$), indicating that perceived workload was rated as lower when they were not required to perform the mental arithmetic task. No differences, however, were found due to age.

4.3. Workload sub-scales

A GLM found a main effect for type of marking for all of the six sub-scales (mental demand, physical demand, temporal demand, performance, effort and frustration), where lower workload was found for the enhanced conditions compared to the standard markings (all $P < 0.05$). Also a main effect was found for type of task for all of the six sub-scales, where lower workload was found when there was no additional task (all $P < 0.05$).

4.3.1. Other subjective measures

The results for the two additional questions are shown below (on a 0–20 scale where lower values indicate that participants were more confident and found the drives easier).

For the confidence question a GLM showed a significant main effect for the type of marking (df = 1,23, $F = 8.31$, $P = 0.010$). As seen in Table 6, participants were more confident in the two drives with enhanced markings than for the two drives with standard markings. Additionally, a significant main effect was found for the type of task used (i.e. no task or an additional task) (df = 1,23, $F = 30.65$, $P = 0.000$). Participants were significantly more confident in the two drives for which they were not required to perform the additional mental arithmetic task.

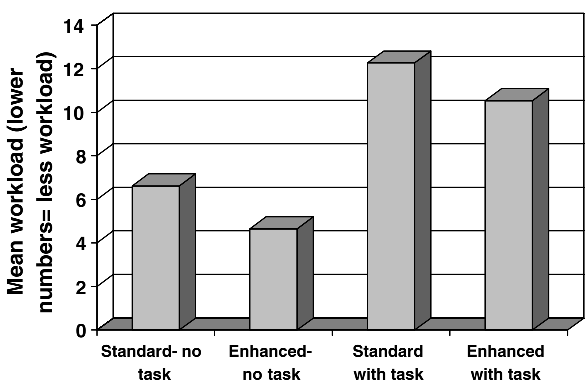

Fig. 1. Mean workload ratings for the four conditions.

Table 6
Mean confidence and difficulty ratings for the four conditions

	Standard marking—no extra task	Enhanced marking—no extra task	Standard marking—with extra task	Enhanced marking—with extra task
Confident of being able to drive safely in the last drive	6.52	4.64	10.6	9.5
How easy was the last drive	7.08	4.72	12.76	10.92

For the difficulty question a GLM showed a significant main effect for the type of marking ($df = 1, 23$, $F = 20.891$, $P = 0.000$), indicating that participants rated the two drives with the enhanced markings as easier than the two drives with the standard markings (see Table 6). Additionally, a significant main effect was found for the type of task used (i.e. no task or an additional task) ($df = 1, 23$, $F = 37.623$, $P = 0.000$). Participants rated the two drives for which they were not required to perform an additional task as significantly easier than the drives during which they performed the additional mental arithmetic task.

5. Discussion

This study investigated the potential safety benefits of enhanced road markings that have high retro-reflectivity in wet conditions. Participants drove in an advanced simulator on a rural road on a wet night with both standard and enhanced edge lines and centrelines. The simulated standard markings were based on those widely used on rural roads in Victoria, Australia. The simulated enhanced markings were based on markings created by using relatively large glass beads to preserve visibility in wet conditions; such markings are also used on many roads in Australia and worldwide. An important feature of this study was that a wide range of objective and subjective response measures were used to measure performance. The results showed that participants drove closer to the target speed of 100 km/h and their speed was less variable with the enhanced markings. Standard deviations of lateral road position, a measure of position on the road relative to the edge line, were significantly lower with the enhanced markings. With enhanced markings, drivers controlled the positioning of the vehicle on the road more accurately. In addition, drivers crossed over the edge and centrelines almost twice as much with standard markings compared to enhanced markings.

These results have important implications for road safety. Reducing the amount of lateral lane deviation and lane crossing errors would be expected to reduce the potential for road crashes, with a corresponding reduction in casualties. This is particularly relevant for rural driving when speeds are usually higher and street lighting is often absent. These lane-keeping errors also occurred during the approach of oncoming vehicles such as large trucks; therefore the potential safety benefit for enhanced markings for rural night driving when there are many large trucks travelling at high speed is considerable.

Mean speed and speed standard deviation were also used as driving performance measures, and it was found that the enhanced markings allowed participants to drive faster and with less speed variation. With the standard markings, participants compensated for the lower visibility by driving more slowly. It might be argued that the enhanced markings could therefore increase the safety risks. However, one of the experimental instructions was for participants to drive as closely as possible to the indicated speed limit, and subjects were closer to this 'target' speed in the enhanced marking conditions, so for the purpose of this experiment producing 'better' task performance. Therefore the authors believe that these data should be interpreted as indicating that drivers were able to drive closer to the target speed because the effort required to drive with the enhanced markings was lower than the effort required to drive with the standard markings. The subjective data provided evidence that this is the case whereby all workload scales were rated as higher with the standard markings.

The benefits of the enhanced markings in reducing driver workload might not be realised fully unless drivers are placed under high workload conditions. Driving is often accompanied by other tasks, such as navigating or operating in-vehicle equipment, which increase workload. Certain traffic conditions, such as the presence of heavy vehicles and overtaking vehicles also increase driver workload. Therefore, any reduction in workload that can be gained from designing better, more visible guidance systems for drivers will free up driver's resources and increase their ability to deal with other demanding situations. This will clearly increase driving safety.

In order to investigate these effects, in two drives in the study participants performed a forced-pace mental arithmetic task while driving. It was expected that the enhanced markings would be particularly beneficial in this condition. Contrary to expectations, although subjective workload ratings were higher in the secondary task condition, the presence of the task did not affect actual driving performance. The mental arithmetic task was clearly not sufficiently demanding to affect driving performance. Although the participants felt that the task increased their workload, they appeared to be able to compensate for this by increasing the effort they expended. In order to elicit driving performance errors, and examine whether these were different for the different types of markings, more demanding conditions would be needed. For example, traffic hazards that substantially increase workload in the driving scenarios might result in increased driving errors, especially with the standard markings. This is partly in accord with a previous study conducted in this simulator that found that although a secondary task significantly increased drivers' perceived workload, driving performance was mainly only affected during unexpected highway hazards such as a pedestrian suddenly stepping onto the roadway (Horberry et al., in press). In any case, the present study found that driving performance was better with the enhanced markings even without any additional task, indicating that even under ideal driving conditions with full attention focused on driving, the enhanced markings were better.

It was hypothesised that older drivers would benefit more from the enhanced markings because of their poorer vision. Contrary to expectations, there were no age differences found in this study. However, the results of this study show that high visibility markings do lead to more accurate, well-controlled driving and this may enhance drivers' ability to cope with unexpected dangers and demanding situations. It is under these conditions that the additional safety benefits of enhanced markings for older driver will most probably be realised.

The findings that more conspicuous edgelines (i.e. the enhanced markings) lead to faster but more controlled driving, greater confidence and reduced driving errors are clearly in line with the work of Johnston (1983) and Ranney and Gawron (1986) reported earlier. Further, in terms of lateral control, the results of this study are in agreement with those of McKnight et al. (1998) who found that lower visibility edgelines were associated with more lateral lane position errors. Therefore a road marking that promotes lateral control should have a positive safety benefit, especially if the markings enable the driver to cope with real world stressors such as glare from headlights and occasional performance of additional tasks.

6. Conclusions

This experiment only considered behaviour in a driving simulator in which a limited number of road scenes were presented. Whether the results found here will generalise to the 'real world' needs to be confirmed by future studies. However, the authors argue that the study was well-controlled, the types of markings were systematically manipulated and the many response measures that were taken generally supported each other. Further, it was undertaken in a well-validated advanced driving simulator- many previous studies have shown that measures derived in this simulator closely correlate to those in real world driving (e.g., Godley, Triggs, & Fildes, 1997). Also, before the actual study was undertaken the project team spent a great deal of time making the scenes as realistic as possible (for example, by getting independent marking experts to evaluate the scenes created). As such, it is argued that the results are a meaningful like-for-like comparison of enhanced and standard markings.

The study found consistently superior results for the enhanced markings in comparison to the standard markings for both the objective driving performance and the workload/subjective data. As such, the findings suggest that important safety benefits might emerge from greater use of enhanced markings on roads around the world.

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