Project PRIME: Enhancing human performance with motorcycle road markings on regular roads

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SUMMARY

Project PRIME is investigating new road markings that demonstrate positive behaviour change for motorcycle casualty reduction. These road markings have been designed as a low-cost solution for road safety and a key research question is whether they are suitable for regular roads that have not been improved through expensive engineering works. This paper reports the findings for regular roads where these unique road markings produced statistically significant reductions in motorcycle speed, improved lateral lane position, and reduced braking and increased use of the markings across collision cluster sites on key motorcycle routes across the West Highlands of Scotland. These findings provide confidence that PRIMEs can be installed on regular roads where motorcycle collisions need to be addressed. Project PRIME has demonstrated major impact in rider safety and was awarded the Prince Michael International Road Safety Award in 2023.

KEYWORDS

Transport human factors, Motorcycle rider, Behaviour change, Road markings, Casualty reduction

Introduction

In the UK, between 2015 and 2020, an average of six motorcyclists were killed and 115 were seriously injured each week in reported road casualties (Department for Transport 2022). This is a picture that is repeated around the world with motorcyclists grossly over-represented in road traffic collision statistics (de Moraes, Godin, Dos Reis, Belloti and Bhandari, 2014; Vanlaar, Hing, Brown, McAteer, Crain and McFaull, 2016, Transport Scotland, 2021).

Motorcyclists are notoriously difficult to engage with road safety initiatives and riders who have not taken further training may develop poor riding styles and lack riding skills to keep them safe. In many incidents, the motorcyclist is the sole vehicle involved and common causes are attributed to a poor turn or manoeuvre, exceeding the speed limit, loss of control, travelling too fast for the conditions or sudden braking (Department for Transport 2021).

In an attempt to reduce road casualties, many governments, road safety agencies and practitioners around the world are adopting the Safe System approach which promotes a transport system free from death and serious injury (Job, Truong, and Sakashita, 2022; Transport Scotland, 2021). A key focus is the fallibility of humans so that the transport system is more supportive of their needs and wider policy requirements.

There are five guiding principles to the Safe System: people make mistakes; people are vulnerable to injury; shared responsibility for road safety; forgiving systems approach; and vision zero where the aim is for no one is killed or seriously injured on the roads (Job, Truong, and Sakashita, 2022).

From these principles, five inter-related pillars have been developed for Safe System design: safe road use, safe roads and roadsides, safe speeds, safe vehicles, better post-crash responses. The current research was conducted in accordance with the Safe System approach and the findings are considered in respect of this in the discussion.

PRIME road markings to enhance human performance

Dedicated road markings, designed as 'Perceptual Counter-Measures' (PCMs) have been shown to influence road user behaviour. These are typically road markings that dictate a desired behaviour by altering how a road user might perceive and process risk factors in the environment around them (Gardener, Tate, Mackie, Stedmon, and Southey-Jones, 2017; Mulvihill, Candappa, and Corben, 2008).

With the current research, a new approach was taken by developing a tool for motorcyclists through the design of 'Perceptual Rider Information to Maximise Expertise and Enjoyment' (PRIMEs). The underlying philosophy of PRIMEs is to provide a road behaviour solution for motorcycle riders using terms that are relevant to them such as expertise and enjoyment (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022). It is also important that as a casualty reduction intervention, PRIMEs are cost effective to install and maintain. PRIMEs should be able to be installed on existing (i.e. regular) roads or incorporated into larger road upgrade schemes.

For motorcyclists safely navigating bends it is important that: speed is suitable for the conditions, position is optimised for entering and travelling through the bend, and braking is minimised. A combined road sign and road marking were investigated in this research (Figure 1).

Figure 1: PRIMEs road sign and 'gateway' road marking

The road marking was designed as a series of three 'gateway' markings positioned on the approach to a bend. The intention was that the road marking would encourage motorcyclists to ride 'through the gap' and use the gateways as a cue to adjust their riding behaviour. Throughout the research programme, the results have demonstrated positive behaviour change (Stedmon, et al, 2021, 2022; Stedmon, McKenzie, Langham, McKechnie, Perry, Wilson, Mackay and Geddes, 2024).

With international interest from road authorities wishing to install PRIME road markings and a keen awareness of limited budgets for road safety, a key question for the research was whether PRIME road markings would be effective on regular roads. In Phase 1 of Project PRIME the trial sites were brought up to the best standard through engineering works to support the research. Moving on from this, trial sites were identified where no works were conducted and which represented typical regular roads where other authorities might install PRIME road markings.

Trial site selection

An initial analysis by Transport Scotland of the Trunk Road Network identified 660 collisions involving motorcyclists between 2013 and 2017. Using STATS19 data (reported directly from Police attending accident scenes) the North-West region was identified as a priority area for motorcycle casualty reduction. BEAR Scotland Ltd (North-West Unit) conducted a further review of collision cluster sites. Between 2008 and 2017, sites within a 100m radius where three or more personal injury accidents (PIAs) involving a motorcyclist or pillion highlighted the A82, A85 and A83 as priority routes (BEAR Scotland, 2019).

Six trial sites were selected for these road trials and were spread over a large geographic area ranging from Crianlarich, Crieff and Stirling. The site represented a range of bends on rural roads with speed limits over 40mph in line with recent casualty statistics (Transport Scotland, 2020) and a range of characteristics (e.g. complex geometry, tightening apexes, descents and inclines prior to bends, bends off fast sections of road). The sites are represented below (Figure 2).

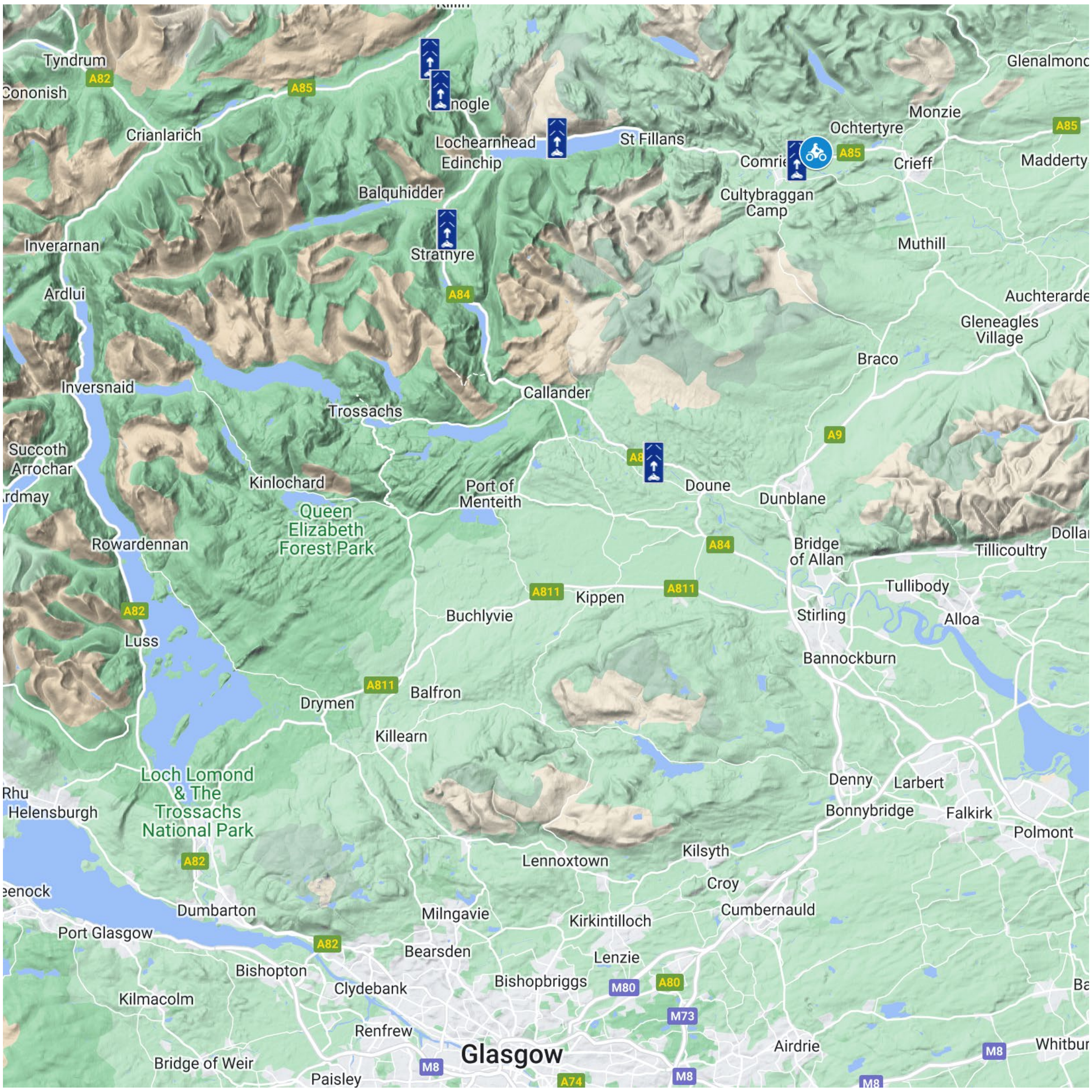

Figure 2: PRIMEs trial sites

A comparison site was also included where data were collected but the PRIME road markings were not installed. Due to the wide variety of bends and road characteristics on the Trunk Road Network, the comparison site was not regarded as experimental control condition (i.e. where identical conditions are usually compared statistically).

Method

This research followed a conventional 'pre- and post-intervention' quasi-experimental approach. Baseline data were compared with data collected once the PRIME road markings had been installed.

Participants

This research relied on an opportunistic sample of motorcyclists. Across the trial sites 4,652 motorcycles were observed and from these 1,542 lead motorcycles were analysed in more detail.

Apparatus

Data were captured at each site using small and inconspicuous weatherproof video cameras typically attached to roadside posts or trees. The cameras captured 1080p video at 60Hz for time periods of at least 20hrs, stored on 512Gb microSD cards. At each site, three cameras were installed facing: towards the rider, behind the rider and perpendicular to the rider a short distance ahead of the last PRIME road marking.

The PRIME road markings were installed using 3M™ Stamark™ High Performance permanent tape. This material provided increased visibility, grip and safety, even in the wet. It also offered high levels of adhesion to the road surface and provided a permanent marking that would not be disturbed by other vehicles (i.e. general traffic and heavy goods vehicles).

Design

The independent variable in this research was the PRIME road markings which had two levels: Baseline (without PRIMEs installed) and PRIME (with PRIMEs installed).

Baseline and PRIME data were collected on a number of occasions, as specified below:

- Baseline 1 and 2 – two separate weekends before PRIMEs were installed
- PRIME 1 – the weekend after PRIMEs were initially installed
- PRIME 2 – six or eight weeks after the PRIME 1 data collection

A range of dependent variables were identified to capture data about the potential influence of PRIMEs on rider behaviour, including speed, lateral position, braking and use of the final PRIME road marking.

Procedure

In a change from the previous research, prior to data collection, trial sites were not upgraded (i.e. resurfacing and new vehicle restraint systems). This was important in order to evaluate PRIMEs on regular roads. Care was also taken to make sure that no changes to the sites were undertaken during the trials (i.e. scheduled road works).

Data were captured during the typical motorcycle season (i.e. May to September) when motorcyclists were most active. Weekends were chosen for data collection as this was generally when motorcyclists ride for leisure/social purposes. During each weekend cameras were set up at the trial sites and recorded all road traffic during Saturday and Sunday from 09:00 to 17:00. Power supplies were replenished through the weekend and cameras were collected on Sunday evenings.

Ethics and risk assessment

An independent review of potential ethical issues was conducted. Approval was granted in accordance with general principles of the British Psychological Society and International protocols. A risk assessment was also conducted in order to safeguard the research activities. Induction training was undertaken so that roadside safety protocols were adhered to and the correct PPE was worn at all times. The design for the PRIME road markings and road sign went through a formal application process for authorisation of non-prescribed traffic signs (Road Traffic Regulations Act 1984: Sections 64 and 65). Approval was granted prior to the trials taking place. Following on from this, independent road safety audits are conducted at regular intervals to oversee the safe installation of PRIMEs at all trial sites.

Data analyses

Baseline 1 and Baseline 2 datasets were compared by conducting a T-Test (*t*) to identify any differences between them. Where any significant differences were observed, effect size was calculated using Cohen's (*ds*) equation. Where the Baseline 1 and Baseline 2 datasets were observed to be the same (i.e. there was no significant difference) they were combined into a single dataset (i.e. 'Baseline'). This was the case in all baseline comparisons reported in this paper.

Speed and lateral position data were analysed using one-way Analysis of Variance (ANOVA) techniques. Where any significant results were observed, effect size was calculated using a partial eta squared (η^2) analysis. Post-hoc Bonferonni-Hoch analyses were conducted in order to determine where significant differences occurred between the datasets. Tests for effect size were conducted using Cohen's (*ds*) calculations.

Braking behaviour and use of PRIMEs datasets were analysed using Chi Square (X^2) tests. Where any significant results were observed, effect size was analysed using Cramér's V (*V*) calculations. Further post-hoc analyses were performed by calculating standardised residuals in order to determine where significant differences occurred between the datasets.

In previous analyses intra-rater reliability was assessed instead of inter-rater reliability (Stedmon et al, 2021). This followed the process set out by Mackey and Gass (2005) where ratings were conducted at different time intervals (i.e. T1 and T2) and then analysed in the same way as inter-rater reliability. Cohen's Kappa (*k*) calculations were conducted for samples of data for speed, lateral position and braking in the 2020 road trials. For speed and braking perfect matches were observed (k=1.0) due to the discrete nature of these data. For lateral position k=0.92 indicating a very high agreement and only minor differences in coding at the thresholds between the three lane positions.

Results

In total 4,652 motorcycles were processed across all the trial sites and from these 1,542 lead motorcycles were analysed in more detail. Results from the trial sites are summarised below (Table 1).

Table 1: Motorcycle numbers throughout the road trials

Trial site	Rider Behaviour				
	Speed	Position at PRIME	Position at Apex	Braking	Use of Gateway
Landrick	Sig	-	Sig	-	Sig
Strathyre	Sig	Sig	-	-	Sig
Glenogle	Sig	Sig/Trend	Sig	Sig/Trend	Sig
Mid Lix	Sig	Sig	Sig	-	Sig
Dalkenneth	Trend	Trend	Sig	Trend	Sig
West Lodge	Sig	Sig	Sig	Sig/Trend	Sig
Lawers Lodge (comparison)	-	-	-	-	-

These results are summarised below:

- **Speed** – statistically significant reductions in speed were observed at 5 of the 6 trial sites and a trend observed at the other trial site
- **Lateral position at the final PRIME road marking** – statistically significant changes in lateral position were observed at 4 of the 6 trial sites indicating that motorcyclists were riding in better positions on approach to the bend. Trends were observed at two trial sites
- **Lateral position at the apex of the bend** – statistically significant changes in lateral position were observed at 5 of the 6 trial sites
- **Braking behaviour** – statistically significant reductions in braking were observed at 2 of the 6 trial sites. Trends were observed at 3 trial sites
- **Use of the PRIME road markings** – statistically significant increases in the use of the road markings were observed at all 6 of the trial sites
- **Comparison site** – as expected, no differences in rider behaviour were observed.

A number of trends in the data were observed. A reduction in speed was found at Dalkenneth ($p=0.19$). For lateral position at the final road marking, at the Glenogle trial site the PRIME 1 result fell just outside of being statistically significant when the Bonferonni-Hoch corrections were applied (i.e. $p=0.026$ rather than $p<0.025$). A positive change in road position was also found at Dalkenneth ($p=0.11$). For position at the apex of the bend, at the Landrick trial site the PRIME 1 result fell just outside of being statistically significant when the Bonferonni-Hoch corrections were applied (i.e. $p=0.033$ rather than $p<0.025$). For braking, a reduction in braking on the bend was found at Glenogle ($p=0.15$) and Dalkenneth ($p=0.10$) and also for total braking at West Lodge ($p=0.13$).

Discussion

Overall, the results for the PRIME road trials provide evidence for a range of beneficial effects of PRIMEs on rider behaviour on regular roads. Across all key measures (i.e. speed, position, braking and use of the gateway) significant effects were observed at different sites during the trials.

There were no instances of statistically significant increases in speed, dangerous positioning, increases in braking or decreased use of the gateways. These observations provide further evidence that PRIMEs did not have a detrimental effect on rider behaviour. As such, even at locations where no statistically significant effects were observed, PRIMEs were no worse than not installing them at all.

Transport Scotland recently published its 'Road Safety Framework to 2030′ (Transport Scotland, 2021). It proposes a Safe System approach to road safety delivery as set out in the National Transport Strategy Delivery Plan (Transport Scotland, 2020). In relation to the concept of PRIMEs, the current research addresses the following pillars:

- safe speeds – speed limits in a Safe System are designed for crash-avoidance and reducing physical impact. Key factors that should be taken into account in any decisions on local speed limits are history of collisions, road geometry and engineering, road function; composition of road users (including existing and potential levels of vulnerable road users); existing traffic speeds, and road environment (Transport Scotland, 2021). With these factors in mind, PRIMEs offer a potential tool for supporting speed limits on regular roads. With the observed reductions in speed and no statistically significant increases in speed, PRIMEs may therefore provide a means for maintaining safe speed limits rather than drastically reducing them. However, coupled with improved position on the road and reduced braking on bends this would appear to be supporting the rider experience more holistically rather than focusing on one specific measure of performance for safety.

- safe road use – road users should pay attention to the road ahead and the task in hand; adapting to the conditions (weather, the presence of other users, etc.); travel at lower speeds; and give sufficient room to all other road users, no matter what their mode of travel (Transport Scotland, 2021). PRIMEs appear to provide motorcyclists with a tool that allows them to adapt their behaviour to the road environment and which other road users may also use as a cue for demanding bends and the presence of motorcyclists. In this way PRIMEs may help ensure that road users are risk-aware, can develop coping strategies for demanding situations, and act appropriately to keep themselves and others safe on the road (Transport Scotland, 2021). This was demonstrated by the positive results for road position both at the final PRIME road marking and at the apex of the bend.

- safe roads and roadsides – the environment is designed to reduce the risk of collision and to mitigate the severity of injury should a collision occur. This can be achieved through design, maintenance and the implementation of strategies to reduce casualties on the roads (Transport Scotland, 2021). This can also be promoted through positive behaviours and safer sharing of spaces, the appropriate use of speed limits and signage that provides a much more affordable and sustainable way to protect the most vulnerable road users. PRIMEs provide a low-cost and easily maintained casualty reduction initiative working in harmony with other interventions such as bike-guard and other vehicle restraint system (VRS) solutions. They can be installed on existing roads quickly and efficiently or incorporated into road upgrade schemes. From the low incidence of braking across the trial sites, this would seem indicate that motorcyclists are generally set up well for these bends but that other effects on position and speed enhance safety further.

Across these strategic pillars PRIMEs have the potential to provide a new and unique contribution to the Safe System approach. There is clear evidence from the research that PRIMEs influence rider behaviour and alongside this an installation toolkit has been developed for others to use in their areas and support the roll-out of PRIMEs more widely.

Conclusion

This research has demonstrated that the PRIME and road markings produced behaviour change on regular roads. There were a range of positive effects through speed reduction, better road position, reduced braking and an increased use of the markings compared to the baseline. Furthermore, no negative behaviours arose from the installation of the road markings. This research expands the scientific knowledge base of previous findings (Stedmon et al, 2021, 2022, 2024) to support the wider incorporation of the new road markings in motorcycle casualty reduction within the Safe System approach to road safety.

References

BEAR Scotland Ltd. (2019). *North West Unit Motorcycle Accident Investigation*. (unpublished report prepared for Transport Scotland, Trunk Road and Bust Operations (TBRO) Directorate. Scheme Ref: 18/NW/0801/042

de Moraes, V. Y., Godin, K., Dos Reis, F. B., Belloti, J. C., and Bhandari, M. (2014). Status of road safety and injury burden: Brazil. *Journal of Orthopaedic Trauma* 28, S45-S46

Department for Transport (2021). *Reported Road Casualties in Great Britain: Motorcycle fact sheet, 2020*. The Stationery Office, London. https://www.gov.uk/government/statistics/reported-road-casualties-great-britain-motorcyclist-factsheet-2020/reported-road-casualties-in-great-britain-motorcycle-factsheet-2020

Department for Transport (2022). *Vehicle Speed Compliance Statistics for Great Britain 2021*. The Stationery Office, London. https://www.gov.uk/government/statistics/vehicle-speed-compliance-statistics-for-great-britain-2021/vehicle-speed-compliance-statistics-for-great-britain-2021

Gardener, R., Tate, F., Mackie, H., Stedmon, A. W., and Southey-Jones, B. (2017). Motorcycle-friendly roads: Applying a customer lens on the journey from identification to implementation. In, *Proceedings of Australasian Road Safety Conference 2017* 10-12 October 2017, Perth Australia.

Job, R. F. S., Truong, J., and Sakshita, C. (2022). The ultimate Safe System: redefining the Safe System approach for road safety. *Sustainability*, 14, 2978. doi.org/10.3390/su14052978

Mackey, A., and Gass, S.M. (2005). *Second Language Research: Methodology and Design*. Mahwah, NJ: Lawrence Erlbaum Associates.

Mulvihill, C., Candappa, N., and Corben, B. (2008). *Evaluation of Perceptual Countermeasures for Motorcyclists Stages 1 and 2: Final Report*. Victoria Australia: Monash University Accident Research Centre.

Stedmon, A. W., McKenzie, D., Langham, M., McKechnie, K., Perry, R., and Wilson, S. (2021). Safeguarding motorcyclists: Trialing new PRIME road markings for casualty reduction. *Transportation Research Part F: Psychology and Behaviour* 83(2021), 333-350

Stedmon, A. W., McKenzie, D., Langham, M., McKechnie, K., Perry, R., and Wilson, S. (2022). Safer road users: Investigating the influence of PRIME road markings on motorcycle rider behaviour. *Transportation Research Part F: Psychology and Behaviour* 83(2021), 368-385

Stedmon, A. W., McKenzie, D., Langham, M., McKechnie, K., Perry, R., Wilson, S., Mackay, M., and Geddes, S. (2024). Project PRIME: road markings for motorcycle casualty reduction (an overview of findings from 2020 to 2022). *Ergonomics* 1-16, https://doi.org/10.1080/00140139.2024.2361304

Transport Scotland (2020). *Reported road casualties Scotland 2019: Key findings report*. Transport Scotland, Glasgow: Crown Copyright. ISBN: 978-1-911672-04-3

Transport Scotland (2021). *Scotland's Road Safety Framework to 2030: Together making Scotland's roads safer*. Transport Scotland, Glasgow: Crown Copyright. ISBN: 978-1-911672-06-7

Vanlaar, W., Hing, M. M., Brown, S., McAteer, H., Crain, J., and McFaull, S. (2016). Fatal and serious injuries related to vulnerable road users in Canada. *Journal of Safety Research* 58, 67-77