PRIME Road Markings for Motorcycle Casualty Reduction in Scotland

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ABSTRACT

This paper presents research of new PRIME road markings in which over 32,000 motorcyclists were manually counted and coded. Analyses indicated that these unique road markings produced statistically significant reductions in motorcycle speed, improved lateral lane position, and reduced braking across 22 sites in the West Highlands of Scotland. This work provides insights into the 'Safe System' approach to support safer motorcycling and casualty reduction.

KEYWORDS

Motorcycle rider, Behaviour, Road markings, World trials, Casualty reduction

Introduction

Around the world motorcyclists are grossly over-represented in road traffic collision statistics (de Moraes, Godin, Dos Reis, Belloti and Bhandari, 2014; Transport Scotland, 2021).

Typically, motorcyclists are around 51 times more likely to be killed on the road than car drivers (Department for Transport, 2019, Transport Scotland 2020). These statistics highlight motorcyclists as one of the most vulnerable road user groups on public roads.

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 2021). In Scotland, motorcyclists represent only 2.2% of all registered vehicles but account for 14% of all Killed or Seriously Injured (KSI) casualties (Transport Scotland, 2020).

In many incidents, only the motorcyclist is involved and the 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 response, the Scottish Road Safety Framework has identified motorcyclists as a Priority Focus Area with a target for a 30% reduction in motorcyclists killed or seriously injured by 2030 (Transport Scotland, 2021).

PRIME road markings to support rider behaviour

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 driver might perceive and process risk factors in the environment around them (Gardener, Tate, Mackie, Stedmon, and Southey-Jones, 2017; Mulvihill, Candappa, and Corben, 2008).

From the motorcyclist's perspective, PCMs have been shown to influence rider behaviour in relation to speed, position, and braking to reinforce better rider behaviour (Hirsch, Moore, Stedmon, Mackie, and Scott, 2017; Hirsch, Scott, Mackie, Stedmon and Moore, 2018).

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 develop solutions that are cost effective to install and maintain. PRIMEs can be installed on existing roads quickly and efficiently or incorporated into road upgrade schemes.

'PRIMEs' provide a platform of innovative tools for motorcyclists with different riding styles. Motorcyclists are then able to adopt these tools and adapt their behaviour on approach to a potential hazard therefore optimising their expertise and enjoyment (and also their safety on the road). Of particular importance to this research programme was the safe navigation of bends. For this to occur, motorcyclists have to make sure that:

- speed is suitable for the conditions
- position is optimised for entering and travelling through the bend
- braking is minimised whilst travelling around the bend

The PRIME road marking design investigated in this research comprised a series of three 'gateway' markings positioned on the approach to a bend. The intention was that the PRIME road marking would encourage motorcyclists to ride 'through the gap' and use the gateways as a cue to adjust their riding prior to the bend (Figure 1).



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

With a series of three PRIME gateway markings, there was potential for riders to adjust their braking point according to the motorcycle they were riding, their own riding style, or perhaps even due to weather and other environmental effects (i.e. in poor weather they might brake one marker back from their usual point).

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 review of collision cluster sites (BEAR, 2019, 2021). 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.

The trial sites were spread over a large geographic area of approximately 750 square miles ranging from Glencoe, Oban, Inveraray, Loch Lomond and towards Stirling and Crieff. They represented a range of bends on rural roads with speed limits over 40mph in line with recent casualty statistics (Transport Scotland, 2020).

Expert reviews were conducted for each potential site (e.g. complex geometry, tightening or double apexes, descents and inclines prior to bends, bends off fast sections of road) and 22 trial sites were identified and categorised as motorcycle cluster (MCL) sites or PRIME trial (PT) sites (Figure 2).



Figure 2: PRIMEs trial sites

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

Method

This research followed a conventional 'pre- and post-intervention' quasi-experimental paradigm, where 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 all the trial sites 32,213 motorcycles were observed and from these 9,919 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 in 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 3MTM StamarkTM High Performance 100 mm wide 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
- PRIME 3 and 4 to investigate the nature of sustained behaviour effects
- PRIME 5 and 6 to investigate the nature of long-term behaviour effects

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.

In addition, rider interviews were conducted at the Green Welly Stop at Tyndrum and Inveraray waterfront as they were both popular meeting points and ride-out destinations for motorcyclists.

Procedure

Prior to data collection, trial sites were upgraded with various measures such as: resurfacing, line repainting, new crash barriers, vegetation removal, vehicle restraint systems (VRS), and motorcycle friendly 'bikeguard' installations. This meant that any extraneous variables were controlled as much as possible so that they would not otherwise influence rider behaviour (e.g. poor road surface, obscured views, potholes, poor safety provisions). Care was also taken to make sure that no changes to the sites were undertaken during the pilot 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 every trial site 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'). Where any difference was observed, Baseline 1 and Baseline 2 were kept as separate datasets and compared individually with the PRIME 1 and PRIME 2 datasets.

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.

Due to project restraints and as the data processing relied on specific and discrete manual counts, one researcher (Prof Stedmon) conducted the data processing and analyses. This researcher reviewed and re-checked data during the data processing activities. During the 2020 trials intrarater reliability was assessed instead of inter-rater reliability (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022). 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 32,213 motorcycles were processed across all the trial sites and from these 9,919 lead motorcycles were analysed in more detail. Results from the 22 trial sites are summarised below (Table 1).

Site	Rider Behaviour				
	Speed	Position at	Position at	Braking	Use of
		PRIME	Apex		Gateway
2020					
Appin House <i>north</i>		Sig			Trend
Appin House <i>south</i>	Sig	Sig	Sig	Trend	Sig
Kingshouse <i>north</i>	Trend	Sig			Sig
Kingshouse <i>south</i>		Sig	Sig	Trend	
Loch Lubhair <i>east</i>		Sig	Sig	Sig/Trend	Sig
Loch Lubhair west	Sig	Sig	Sig	Sig	Sig
Rob Roy's Dip east 1		Sig		Trend	Sig
Rob Roy's Dip east 2		Sig	Sig	Trend	Sig
Rob Roy's Dip west 1	Sig	Sig	Sig	Trend	Sig
Rob Roy's Dip west 2	Sig	Sig	Sig	Trend	Sig
2021					
Taynuilt	Sig		Sig	Trend	Sig
Inveruglas	Trend	Trend	Sig	Sig	Trend
Runacraig – <i>north</i>	Sig	Trend			Sig
Runacraig – <i>south</i>	Sig	Trend		Sig	Sig
Dunira	Sig	Sig	Sig	Sig/Trend	Sig
Bonawe	Sig		Trend	Trend	Trend
Landrick Bends	no effect	no effect	no effect	Trend	no effect
2022					
ZUZZ		Sig	Sig	Sig/Trond	Sig
Dalinaniac Dulpit Dock		Sig	Sig	Sig/Trend	Sig
Pulpit ROCK		Sig	Sig	Sig/Treflu	Sig
Middle Kames	Trand	Sig		Sig	Sig
Salmon Draft north	Sig	Sig		Sig/Trond	Sig
Salmon Draft couth	JIB	Sig	Sig	Sig/ Trenu	Sig
Samon Dian – Soull	no offort	Sig	JIB	no offect	Jig
CUTTICK	по ејјест	no ejject	по ејјест	no ejject	no ejject

Table 1: Results for PRIME road markings across the 22 trial sites

These results are summarised below:

- **Speed** statistically significant reductions in speed were observed at 10 trial sites. Trends were observed at four other sites
- Lateral position at the final PRIME road marking statistically significant changes in lateral position were observed at 15 trial sites indicating that motorcyclists were riding in better positions on approach to the bend. Trends were observed at three other sites.
- Lateral position at the apex of the bend statistically significant changes in lateral position were observed at 13 trial sites. A trend was observed at another site.
- **Braking behaviour** statistically significant reductions in braking were observed at nine trial sites. Trends were observed at 15 other sites.
- Use of the PRIME road markings statistically significant increases in the use of the road markings were observed at 18 trial sites. Trends were observed at three other sites.

At the comparison sites (indicated in *italics* in Table 1), as expected, no differences in rider behaviour were observed. At one site a trend for reduced braking was observed but this was due to temporary traffic management activity affecting traffic flow on specific data collections periods.

Rider interviews indicated that the majority of motorcyclists were supportive of PRIME road markings and felt they could be particularly useful to inexperienced riders or tourists with many riders stating that "anything that makes the roads safer is a good thing".

Discussion

Overall, the results for the PRIME road trials provide strong evidence for a range of beneficial effects of PRIMEs on rider behaviour on a range of bends. Across all three key measures (i.e. speed, position and braking) 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 PRIME 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' outlining a long-term goal for road safety where no-one dies or is seriously injured by 2050 (Transport Scotland, 2021). It proposes a 'Safe Systems' 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 where roads have already been brought up to the best possible standard. 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 may 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 a 'Safe System' approach. There is clear evidence from the research conducted over the last 3-years that PRIMEs influence rider behaviour and it is important to begin planning for an implementation phase of work and address further research questions that will underpin the roll-out of PRIMEs more widely.

The project consortium have identified representatives from a Local Authority in Scotland with an interest in installing PRIMEs on their roads. This would provide an opportunity to widen the scope of PRIMEs in Scotland while also providing also ideal testbed for trialling a PRIMEs installation process (i.e. a user guide for authorities and councils so they can install PRIMEs without the need for expensive research).

Conclusion

This paper summarises a 3-year programme of PRIME road trials in Scotland funded by Transport Scotland and the Road Safety Trust. Throughout this work and the wider context of psychological theory, the approach taken has provided a planned and incremental development of understanding and building of evidence to take the work forward.

To date, 32,213 motorcycles have been manually counted and coded throughout the West Highlands with 9,919 lead motorcycles analysed in detail to understand the potential influence of PRIMEs on rider behaviour.

As far as the project consortium are aware, this makes the work the largest motorcycle behaviour investigation of its kind. Overall, the scientific evidence supports the concept that PRIMEs influence rider behaviour in positive ways by reducing speed, improving road position and reducing braking.

These findings underpin Transport Scotland's 'Road Safety Framework to 2030' that has identified motorcyclists as a Priority Focus Area with a target of 30% reduction in motorcyclists killed or seriously injured by 2030 (Transport Scotland, 2021).

The concept of PRIME gateway markings provides a simple and very cost-effective solution to help reduce single vehicle crashes on our roads (which are one of the main collision types for motorcycles).

The evidence shows that if PRIMEs are installed they are used by motorcyclists and there have been no instances of a significant increase in speed, dangerous positioning, or increases in braking. These observations provide further evidence that PRIMEs did not have a detrimental effect on rider behaviour. In addition, since the start of the trials there have been no motorcycle injury collisions at any of the previously identified cluster sites.

The findings support the development of bespoke motorcycle road safety measures by Transport Scotland that provide an important step in reducing motorcyclist road casualties. By demonstrating the positive influence of PRIMEs on rider behaviour and rider safety, this work showcases Transport Scotland as a leader in this initiative for the UK and beyond.

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