An analysis of driver behaviour through rural curves: Exploratory results on driver speed

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Abstract

Speed, whether above the speed limit or too fast for the conditions, is a significant contributor to fatal and serious injuries at curves on rural roads. The driving behaviour of 40 motorists was assessed using an instrumented vehicle. This vehicle tracked driver behaviour through around 200 curves on a set driving route. Factors including speed, acceleration, side force and lane position were recorded for each driver. Details regarding the design elements of the route were also collected, including curve severity, direction (left or right), horizontal alignment, grade and cross slope. This paper provides initial results for driver speed behaviour through different types of curves, and discusses the implications of the findings.

Introduction

Road crashes result in a significant number of deaths and serious injuries every year. The high incidence of crashes on rural roads has been identified in various countries. IRTAD (2010) report figures for fatal crashes, including those outside urban areas in many countries. These range from a low of 46% in Japan, to a high of 79% in Spain, with the average of all countries providing data being 62%. In the UK 58% of all deaths, and 41% of deaths and serious injuries occurred on rural roads (King & Chapman 2010). In the US, rural crashes accounted for 57% of fatalities, despite less than a quarter (23%) of the population living in rural areas (NHTSA 2007). The rate of crashes (per km travelled) was 2.5 greater than for urban roads.

The situation is also similar in Australia. In a review of road safety on rural roads, Tziotis et al. (2006) calculated that 60% of fatal crashes in Australia occur on the rural high speed road network resulting in over 1,000 fatalities per year in Australia, and more than 22,000 injuries. A number of road environment factors were identified as contributing to these crashes, including the road condition, road design, the roadside environment and speed. The predominant crash types identified were vehicles travelling ‘off path’ (i.e. run off road) followed by vehicles travelling in the same direction (e.g. side swipes, lane changes and rear end crashes), and opposite direction (i.e. head-on) crashes.

Curves appear to have an elevated level of risk, producing a significant amount of all rural crashes. For example, Steyer et al. (2000) report that around half of all rural road crashes in Germany occur at curves. Retting and Farmer (1998) report that around 40% of fatal roadside crashes in the US are at curves. A report by the OECD (1999) suggests that relatively high numbers of crashes on rural roads occur at curves when compared to tangents and that run-off-road and head-on crashes at these locations are a particular problem. It was suggested that isolated curves or the first curve in a series are of greatest danger particularly as the result of inappropriate speed and lane position. Cenek et al. (2011) identified that in New Zealand, loss of control on curve crashes represented around half (49%) of all injury crashes in 2009 on rural state highways. That study identified that around 26% of the rural state network is curved (defined as having a curve radius of 500 m or less), meaning that crashes at these locations are vastly over-represented.

Charlton & de Pont (2007) discuss three causative factors that may have an influence on crashes at curves. It is suggested that attentional demand may be higher at curves than on straight roads, and that this is exacerbated by higher speeds. Misperception of speed and curvature, especially on approach and at curve entry, was suggested as another factor in crashes at curves. Charlton & de Pont provide evidence to suggest that misperception of curvature is 'relatively common'. Wooldridge et al. (2003) also suggest that crashes may occur at curves when there is a disparity between the perceived safe speed of the curve, and the actual speed at which the curve can be safely negotiated. They suggest that driver expectation based on prior experience plays a large part in safe curve negotiation, and that fewer crashes occur at curves that conform to driver expectations. The third cause suggested by Charlton & de Pont is that motorists have difficulty maintaining lateral position through a curve, leading to a loss of control.

Turner (2009) identified that speed was thought to be a major contributor to crashes at curves. This study reviewed the types of crashes on rural roads that were thought by police to be caused by speed (typically defined as 'too fast for the conditions' or above the speed limit). This is a relatively coarse measure of causality as often police do not attend the scene of a crash, or when they do, they may have a limited amount of information available to form an accurate judgement of crash causation. However, the most common crash types in order of occurrence were:

- Off path on curve (i.e. running off the road while negotiating a curve)
- Off path on straight
- Vehicles travelling in opposing directions colliding
- Overtaking.

Off path on curve was by far the most common crash type, with around 80% of all rural speed related crashes. Compared with 'non speed related' crashes (i.e. where speed was not indicated as a contributing factor) this crash type is also over-represented. In non speed crashes, off path on curve crashes accounted for only 20% of crashes.

Despite many years of research on this topic, crashes at curves still occur in significant numbers, and as identified above, many are related to speed. In order to explore this issue, a study was undertaken to determine behaviour of drivers through curves. A number of such studies have been undertaken over the last few decades (e.g. Johnston, 1982; Fildes, 1986; Campbell et al., 2008), but advances in data collection technologies now allow more detailed and comprehensive information to be collected. This study utilised an instrumented vehicle to collect continuous data on speed and other behaviour through multiple curves. A number of different variables were collected, creating a rich data source which will enable a range of hypotheses relating to driver curve negotiation to be tested.

The study upon which this paper is based assesses broader issues based on the variables collected, including road design elements, traffic management, driver lane position etc. However, this current paper focuses on initial results obtained on driver speed through high risk and low risk curves.

Method

Data on driver behaviour was collected using an instrumented vehicle. Each driver travelled a set route on their own in this vehicle. A total of 40 male subjects were included, 20 with limited driving experience (less than three years) and 20 with more experience (15 years or more). Males were selected to reduce study variance, but also because this is a higher risk group of drivers. All recruited drivers were unfamiliar with the test route.

The vehicle was fitted with devices to measure speed, acceleration/deceleration, side force, GPS location (all collected using ARRB's GipsiTrac and associated devices; see ARRB, 2015), lane position, and distance to vehicle in front (collected using a Mobileye device; see Mobileye, 2015). Video images of the view in front of the vehicle were also collected.

Subjects were recruited using a variety of means, including social media, and other sources of advertising. Information was collected for each driver, including details on driving experience (including on rural roads), and type of vehicle normally driven. Information was also collected on attitudes to driving through the Driver Behaviour Questionnaire (DBQ; Parker et al., 1995).

The study commenced with subjects travelling 13 km along an urban arterial route to the start of the test route. This allowed a period of familiarisation with the vehicle. Journey time to the start of the route was approximately 16 to 18 minutes. This route had various types of delineation, including centre and edgeline marking throughout the route, and a mixture of advance warning signs and curve advisory speeds at more severe curves. The semi-rural test route itself was 21.9 km, taking approximately 30 minutes. At the end of the route, drivers negotiated a roundabout and returned along the same route. The journey to the start of the test route, route negotiation, and return to the starting point took around 1 hour and 35 minutes.

The route was a hilly area on the edge of Metropolitan Melbourne, and involved a mixture of speed environments. In some locations it passed through small townships, while in others it was quite rural. With the mixed nature of development along the route, the speed limit varied between 80km/h and 60 km/h. A higher speed environment would have been preferred, but this was not possible given study constraints (particularly travel time to the starting point).

There were many curves along the route, some of which were quite severe with high speed approaches. There were 101 curves for each direction of travel, giving a total of 202 curves over the whole route. The start of a curve was defined as the point on the road where the curve radius fell below 1000m, or where the curve changed direction when the radius was already below 1000m. The end of a curve was defined as the point at which the curve increased above 1000m, or where it changed direction.

Data was categorised by the point within the curve. Data for the 40m prior to curve commencement was classed as the 'approach'; the point at which the radius fell below 1000m was the 'start'; the segment between the start and point of curve minimum was the 'to minimum'; the point of minimum radius was 'minimum'; the segment between the minimum and curve end was the 'departure'; and the point at which the curve finished was the curve 'end'.

Calculations were made for each curve (based on data collected) of curve start point, point of minimum radius (i.e. the most severe point of the curve in terms of curvature), curve length, and curve direction. An estimate of curve risk was also calculated. This risk assessment was based on previous literature on this topic. The measure used for this study was based on a calculation of the difference between approach speed and speed at minimum curve radius. This was identified by several prominent studies (Turner & Tate, 2009; Krammes et al.,1995) as the most sensitive measure of crash risk for curves. The 20 highest risk curves, and 20 low risk curves were identified, and included in this study for analysis.

Data was excluded where drivers were following another vehicle, during periods of rain (defined as when the wipers were in use) or when roadside activity was likely to influence behaviour (e.g. pedestrians, road works).

Results

The results presented here relate to driver speed through the different curves, and at different points on approach and through the curve. This includes an assessment of speed against some design elements of the curve; and speed through high risk and low risk curves. An assessment was also made of difference in driving speed between young and experienced drivers. Other factors of interest are being evaluated and will be published separately.

All results relating to group differences are statistically significant at least to 0.05 level unless indicated otherwise (based on t-tests, applying a Bonferoni correction for use of multiple tests).

The first analysis shows the relationship between curve radius and speed (Figure 1). This presents the average speed for each curve (across all drivers). It is clear that as the curve radius decreases, the mean speed reduces. This finding is as expected based on road design guidance, where the relationship between vehicle speed, curve radius, pavement superelevation, friction between tyre and road surface and gravity is well documented (see Austroads, 2010). It is only really below a 100m radius that speeds fall consistently below 55 km/h. From this point there is a sharp reduction in speeds, to a low of 30 km/h with a radius of 20m (quite a severe bend).

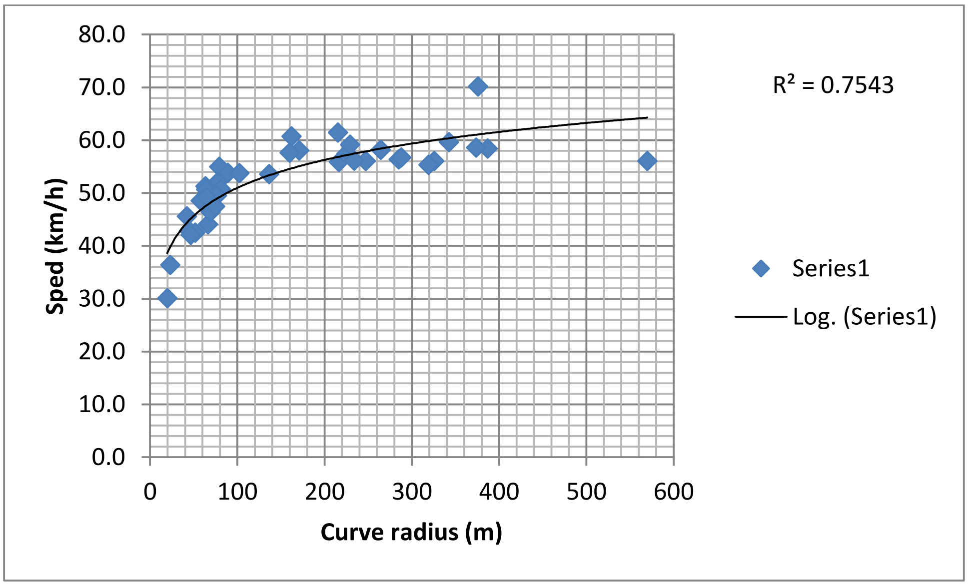

Figure 1. Mean speed by curve radius

Figure 2 shows the speed reduction that occurs from the start of the curve to the point of minimum curve radius. Again, there is a clear relationship between radius and the speed behaviour, with the greatest reduction in speed occurring for the most severe curves.

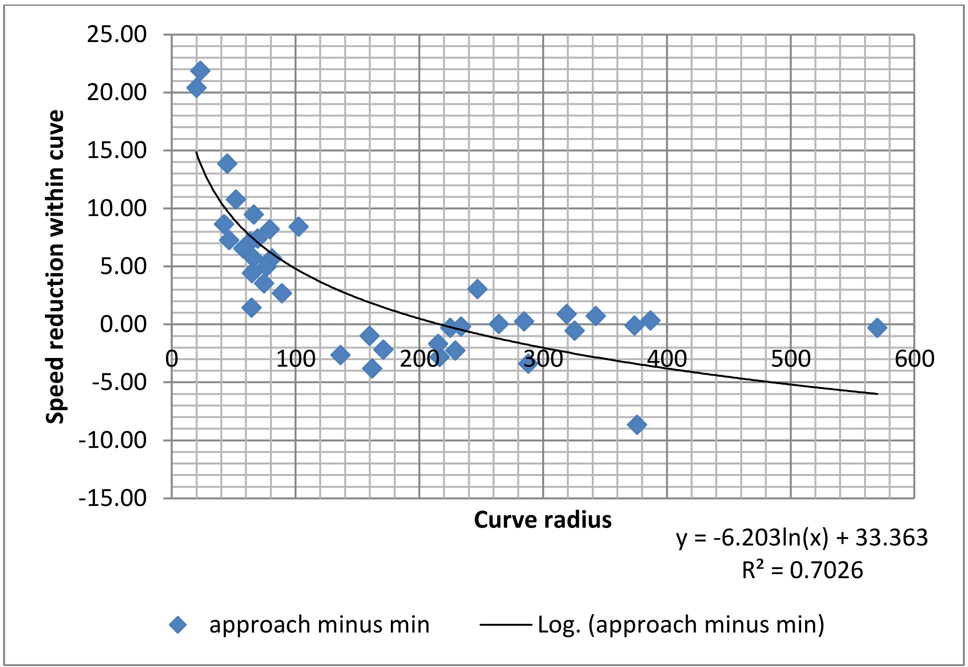

Figure 2. Mean speed reduction by curve radius

Figure 3 shows the reduction in speed based on the calculated crash risk of the curve (defined as the difference in approach speed, and the speed at the point of minimum curve radius).

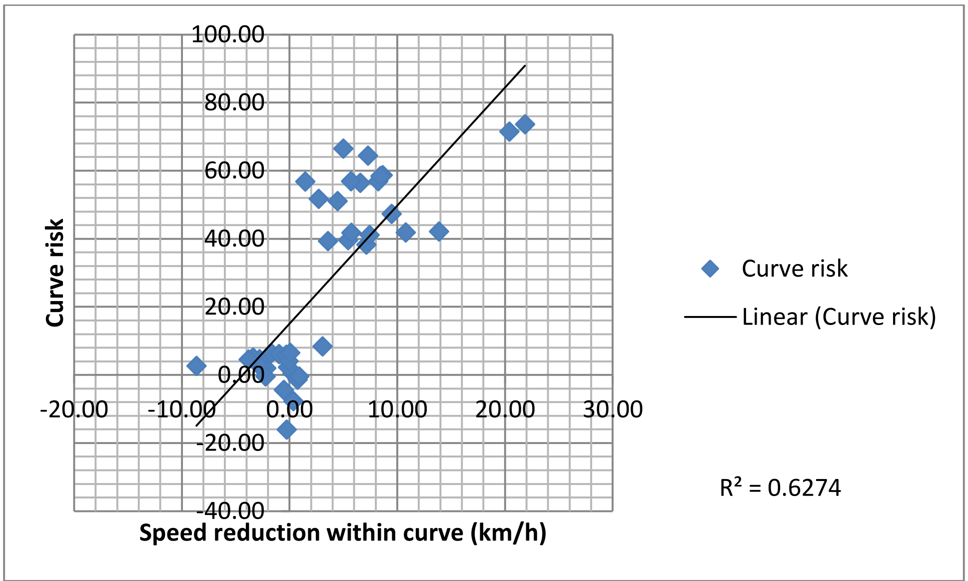

Figure 3. Mean speed reduction by curve risk

Although there is a broad trend for greater speed reduction with higher risk, the relationship is less clear than for curve radius. The two categories of curves (low and high risk) can be clearly observed. Within each of these two groups there is a degree of variance, indicating that although there is a relationship between speed reduction and risk, this is not clear-cut within the two types of curve.

The next set of analyses show speeds at different points throughout curves, comparing high and low risk curves. Mean speeds were lowest through the high risk curves (52.3 km/h compared with 58.5 km/h). Speeds are lower at all points through the curve, with the minimum speed coinciding with the point of minimum curve radius, as shown in Figure 4:

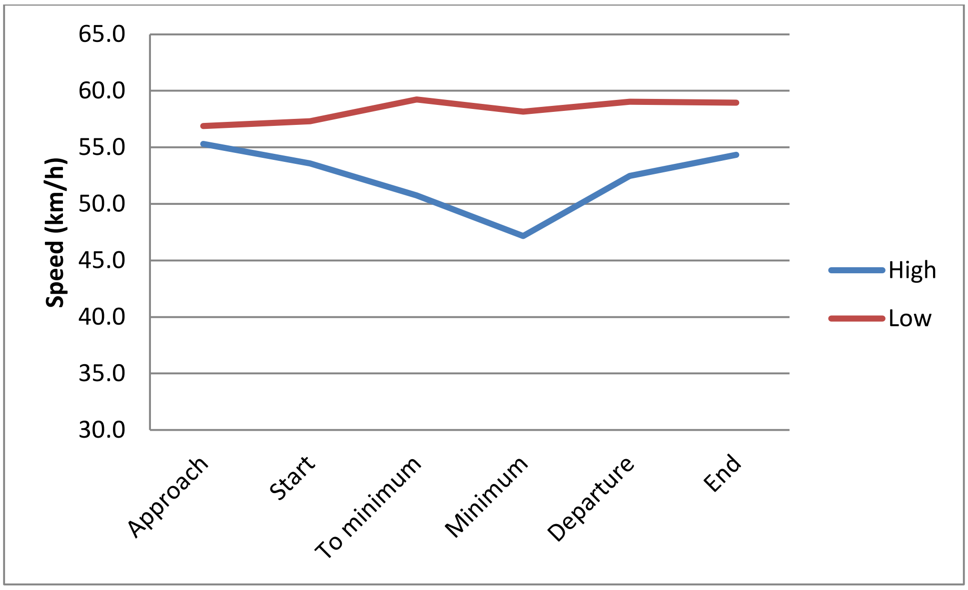

Figure 4. Mean speed by curve risk type

On closer analysis, several things are apparent. For the high risk curves, it appears that speed reduction may have commenced in advance of the 40m buffer used in this analysis, given the mean speed at approach is lower than for low risk curves. It is also apparent that speeds had not returned to the pre-curve level at the end of the curve (10m beyond where the curve radius exceeded 1000m).

A separate analysis was conducted for left versus right curves. This can be seen graphically in Figures 5.

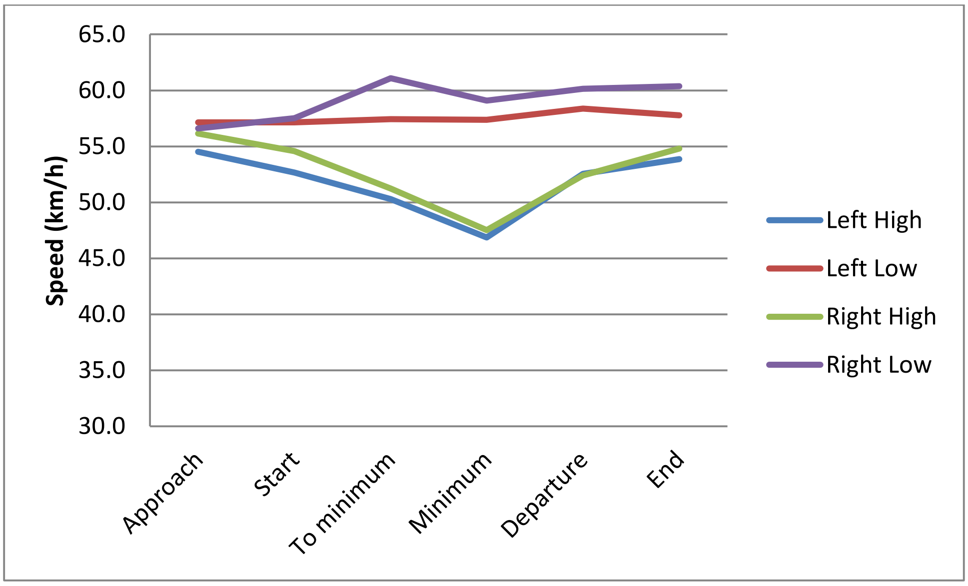

Figure 5. Mean speed by curve risk type and direction

The driving behaviour for both left and right curves was similar, although it is clear that speeds are higher for right curves than for left for both high and low risk curves. For high risk curves, the higher speeds occur when approaching the curve minimum (differences were not statistically significant at minimum, departure or curve end).

Given that speed data is continuous (i.e. gathered every few metres along the roadway) and information was also available on elapsed time for each driver, it was possible to make an accurate calculation of vehicle acceleration and deceleration. Figure 6 shows the result for (a value above 0 m/s/s) and deceleration (values below 0 m/s/s) through different types of curves.

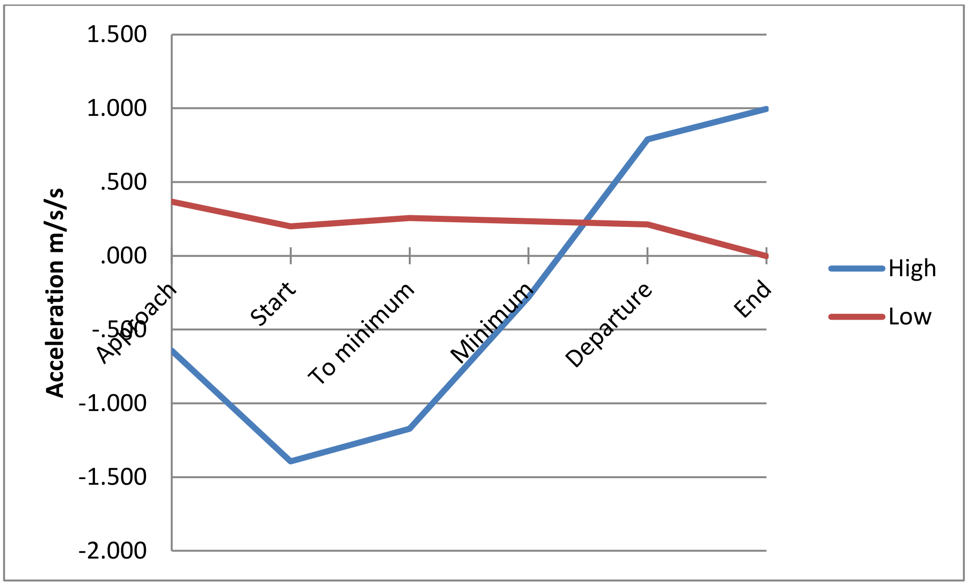

Figure 6. Mean acceleration/deceleration through curves of different risk

It is clear that deceleration has commenced in advance of the curve approach point for high risk curves, and is at its maximum level at curve start. Deceleration continues on approach, and beyond the point of curve minimum. Vehicles are accelerating at curve departure, and continue to do so through curve end.

Lastly, a comparison was made between driving speeds of young drivers and experienced drivers. Figure 7 shows that there is no clear difference in speeds based on driver experience. Although the results were statistically different (except at the point of curve minimum), the results were not at all substantive, particularly for the high risk curves

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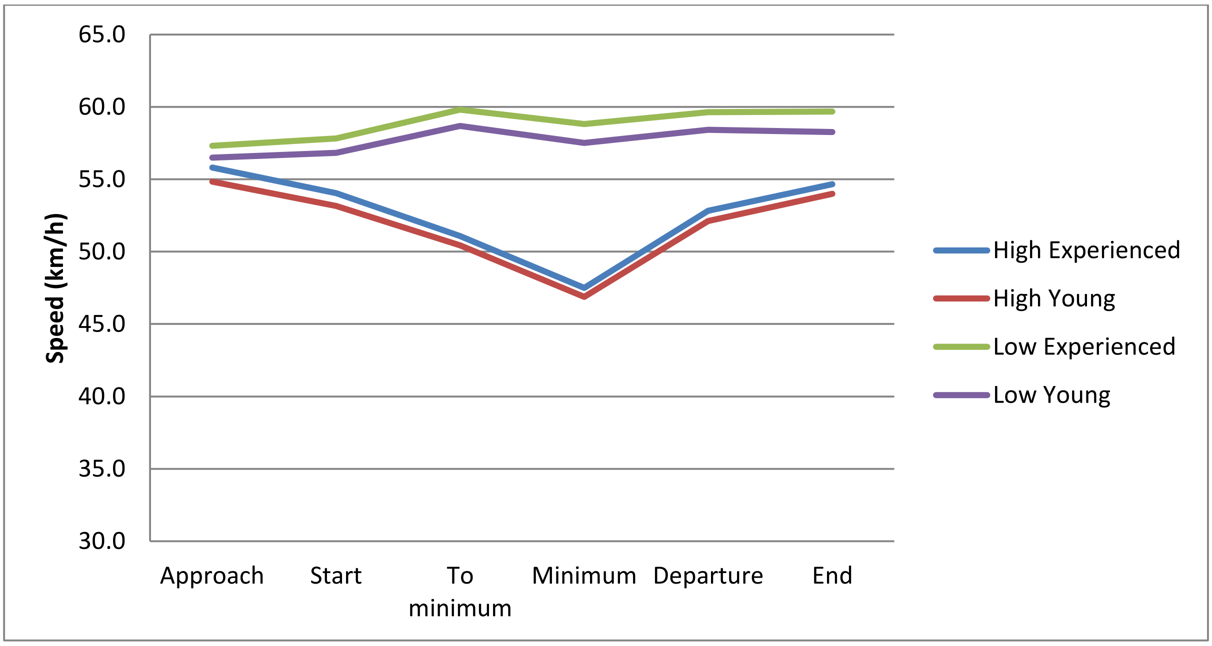

Figure 7. Mean speed by driver experience

Further analysis has been undertaken on difference by driver experience for other driving behaviours, and will be reported in future.

Discussion

It appears that driver selection of speed through curves is highly correlated to curve radius. Drivers seem highly attuned to this element of curve design when making decisions about an appropriate speed. However, it was also noted that these reductions only really commence below a curve radius of 100m. This is interesting, as although risk is greatest for curves below this radius (Veith et al., 2010 suggest the risk is six times greater than for straight roads), there is still a greatly elevated risk for curves with a greater radius (i.e. a less severe curve). The risk for curves with a radius of less than 400m is double that of straight roads, and as highlighted by Levett (2005), curves in this band are far more common, and may (in aggregate) form the greater risk for drivers. Measures to highlight the risk for curves of less than 400m, and the requirement for speed reduction, would be desirable. Jurewicz et al (2014) suggest that categories of curve should be defined based on risk, and differential forms of delineation used for individual curves depending on this category. The findings from this study tend to support this approach, with different curves likely to require different methods for highlighting severity and the appropriate speed.

Speed reduction based on curve risk was less clear-cut within the two broad risk bands (high risk and low risk curves). Within the high risk curves, the amount of speed reduction from curve start to curve minimum was relatively independent of curve risk. This may be because speed reduction had already commenced well in advance of the curve. It would be possible to assess this issue with further analysis.

Speed patterns within curves were as would be expected. Speeds were lower at all points for high risk curves, and the lowest speeds (at least when broadly banding curve segments) occurred at the curve minimum. The result indicating higher speeds through right curves is interesting. Right curves are known to have higher risk (Kloeden et al., 1997; Levett, 2005), a finding that was confirmed from an analysis of crashes on the test route. In an analysis of crashes from the VicRoads crash database (VicRoads, 2014) it was identified that 55% of crashes at curves occurred at a right hand bend. The higher speeds at right hand curves therefore deserves further attention to determine additional risk factors, and to help to identify the means to address these.

One particularly interesting finding from this study was that deceleration continued through and beyond the curve minimum point for high risk curves. Given this is a high risk location it is highly desirable that drivers will have already fully decelerated by this point. Although there are some indications from previous research confirming this finding, road design standards assume that speed reduction is complete at curve start, let alone at this point later in the curve (Austroads, 2010). This finding could have implications for design guidance. Further analysis is required to determine the situations (e.g. the types of curves) where this issue is most prevalent. Given the data set created through this study, this is very feasible. Mechanisms to ensure speed reduction is completed before curve minimum would most likely reduce crash risk. Options need to be explored regarding how this might best be achieved. Such options might include signs located further in advance of curves.

The result indicating no substantive difference for different drivers with different levels of experience is interesting. It could have been expected that young drivers would have exhibited higher speeds, especially through high risk curves, given the higher risk of this group. The opposite was observed in this sample, as young drivers showed lower speeds at all points through both low and high risk curves (the only exception being at the point of minimum curve radius for high risk curves where there was no statistically significant difference). It may have been that young drivers were more cautious in this sample because they were being monitored, or that they are more cautious in selection of speed through curves in general (at least from short exposures to rural driving). Given that some quite extreme behaviours were observed in the sample (e.g. very high speeds and side force by individual drivers through individual curves) despite being observed, it is possible that both situations may be true. It is possible that issues in addition to speed selection are significant in the elevated crash risk of young drivers.

There are a number of limitations to this study. These include that drivers were driving in an unfamiliar vehicle, and were being 'observed'. Despite a period of familiarisation prior to reaching the test route (and some settling of behaviour towards 'normal'), it is possible that drivers were not performing as they normally would. Secondly, the driving route in this study was a constrained hills environment with a maximum speed limit of 80km/h. Although some quite severe curves (in terms of the required speed reduction) were able to be included in the study, analysis of a higher speed environment would be desirable. Thirdly, there are a number of elements that differ between curves, including traffic management and delineation (such as presence of advance warning signs and chevron alignment markers). Although the large number of curves included in this study will compensate for such differences to some extent, it could be expected that these elements will also have an impact on driver selection of speed. Further analysis including these elements is required to help determine their actual impact.

Due to these limitations, generalising of the findings from this study to other contexts should be done with caution.

The data set created through this study will continue to be explored, including the analysis of other behaviours. Assessment of side force and lane position will be important to more fully understand driver behaviour through curves, as will the relationship between these variables and speed. This additional analysis will be presented in future.

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