# Lean Angles and Lane Positions of Motorcyclists

# Schräglagen und Kurvenlinien von Motorradfahrern

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# 1 Abstract


According to the official police road accident database in Austria, run-off-the road accidents in left-hand curves are the most frequent accident type involving motorcycles. “Corner cutting” is a potential cause of such accidents, especially when forward visibility is poor. Previous research has shown that riders’ tolerance to roll angles, i.e. to leaning their motorcycles into a curve, is an issue in crashes in left-hand curves. Accordingly, two studies were initiated based on the current state of knowledge. One of these studies focused on roll angles, the other looked at a potential countermeasure to motorcycle crashes in left-hand curves.

In one of the studies, existing video footage and freeze frames shot in two different curves in Carinthia were reused to measure roll angles and capture other information like lane position, riding style and type of motorcycle.

The other study developed and investigated the impact of the use of road markings painted close to the centre line in tight left-hand curves with poor forward visibility. An impact is expected given the strong belief among motorcycle riders that road markings are slippery and driving over them should be avoided. In this study, three video cameras were placed at nine curves on motorcycle routes, one at the beginning, one at the vertex and one at the exit of each of the curves. The curves were selected based on accident records and infrastructure issues. Two different road marking designs were tested. Automatic image processing was used to identify motorcyclists and their lane position. Other information on the motorcyclist was captured with the assistance of a graphical user interface. While statistically significant results were found for both road marking designs, there were some differences in their respective impacts.

The use of road markings painted close to the centre line in narrow left-hand curves was shown to be an effective intervention at locations with a high accident risk and a high level of corner cutting. Based on the results of the study on roll angles, more accurate advice could be provided to motorcycle riders approaching a curve. Both studies indicate that more research is needed on roll angles and motorcyclists’ fear of exceeding a certain roll angle and that new countermeasures should be developed to address the impact of this phenomenon.

# 2 Zusammenfassung

Den offiziellen Unfallstatistiken in Österreich zufolge sind Abkommensunfälle nach rechts in Linkskurven der häufigste Unfalltyp bei Motorrädern. Kurvenschneiden bietet sich als Erklärung dafür an, überhaupt in Kurven mit geringer Sichtweite. Jüngst veröffentlichte Forschungsarbeiten haben gezeigt, dass die Schräglagentoleranz, also die Fähigkeit von Motorradfahrern, ein bestimmte Schräglage in einer Kurve zu erreichen, bei diesen Unfällen eine wesentliche Rolle spielen könnte. Um tiefer in die Materie einzudringen, wurden zwei Studien durchgeführt, die zwei verschiedene Aspekte des Unfallrisikos in Linkskurven untersuchten.

Für eine der beiden Studien wurden Video und Standbilder benutzt, die ursprünglich als unmittelbare Rückmeldung für Teilnehmer eines Fahrsicherheitstrainings für Motorräder gedacht waren. Dieses in zwei Kurven im Liesertal in Kärnten aufgenommene Material wurde schon einmal für wissenschaftliche Zwecke genutzt, es wurden Kurvenfahrlinien von Motorradfahren untersucht. Diesmal wurden die von den Motorradfahrern eingenommenen Schräglagen zusammen mit anderen Parameter wie Kurvenlinie, Kurvenfahrstil und Typ des Motorrads als Bezugsgrößen erhoben.

Die andere Studie beschäftigte sich mit der Frage, ob vermutlich aus Schräglagenangst resultierende Unfälle mit Bodenmarkierungen bekämpft werden können, die in betroffenen Linkskurven neben der Mittellinie aufgebracht werden. Es wurde erwartet, dass Motorradfahrer – wegen ihres starken Glaubens an die Rutschigkeit von Bodenmarkierungen – einen Bogen um diese machen würden. Mittels dreier Videokameras, je einer am Beginn, dem Scheitel und dem Kurvenausgang, wurden die Fahrlinien von Motorradfahrern und auch hier einige Bezugsgrößen bestimmt. Zwei verschiedene Formen von Bodenmarkierungen wurden in neun Kurven erprobt. Die vollständige Auswertung mittels automatischer Bildverarbeitung gelang nicht, die meisten Informationen wurden letztlich mittels einer eigens entworfenen Eingabemaske beurteilt. Die Auswertung ergab statistisch signifikante Veränderungen der Fahrlinien in der gewünschten Art und Weise. Nur bei einer Kehre wurden nachteilige Effekte beobachtet.

Die Aufbringung von Bodenmarkierungen nach der Mittellinie in engen, unübersichtlichen Linkskurven erwies sich als eine effektive Art, Fahrlinien von Motorradfahrern zu beeinflussen, zumindest in Kurven mit hohem Unfallrisiko und häufigem Auftreten von Kurvenschneiden. Aufgrund der Erkenntnisse über typische Schräglagen könnten zutreffendere Informationen über sinnvolle Kurvenhöchstgeschwindigkeiten für Motorradfahrer kommuniziert werden. Beide Studien zeigten weiteren Forschungsbedarf auf: Das Phänomen Schräglagenangst und mögliche Maßnahmen gegen daraus resultierende Unfälle werden gebraucht.

# 3 Introduction

Although the title of this paper uses the term “lean angle”, the paper will use the technical term “roll angle”.

## 3.1. Motorcycle Accidents

Worldwide, 286,000 riders of powered two-wheelers (PTW) lose their lives on the road annually (World Health Organization , 2015). 3,650 motorcyclists die on Europe’s roads every year (European Road Safety Observatory, 2016), while in Austria around 4,000 motorcycle accidents occur on average. One in five road accident fatalities is a motorcyclist (data: Statistik Austria; own analysis). According to a recent in-depth study published by KFV (Winkelbauer et al, 2017), the main causes of motorcycle accidents are “speed” and “unpredictable behaviour of other road users”. The same study revealed road alignment to be the – by far – most frequent contributing factor (Figure1).

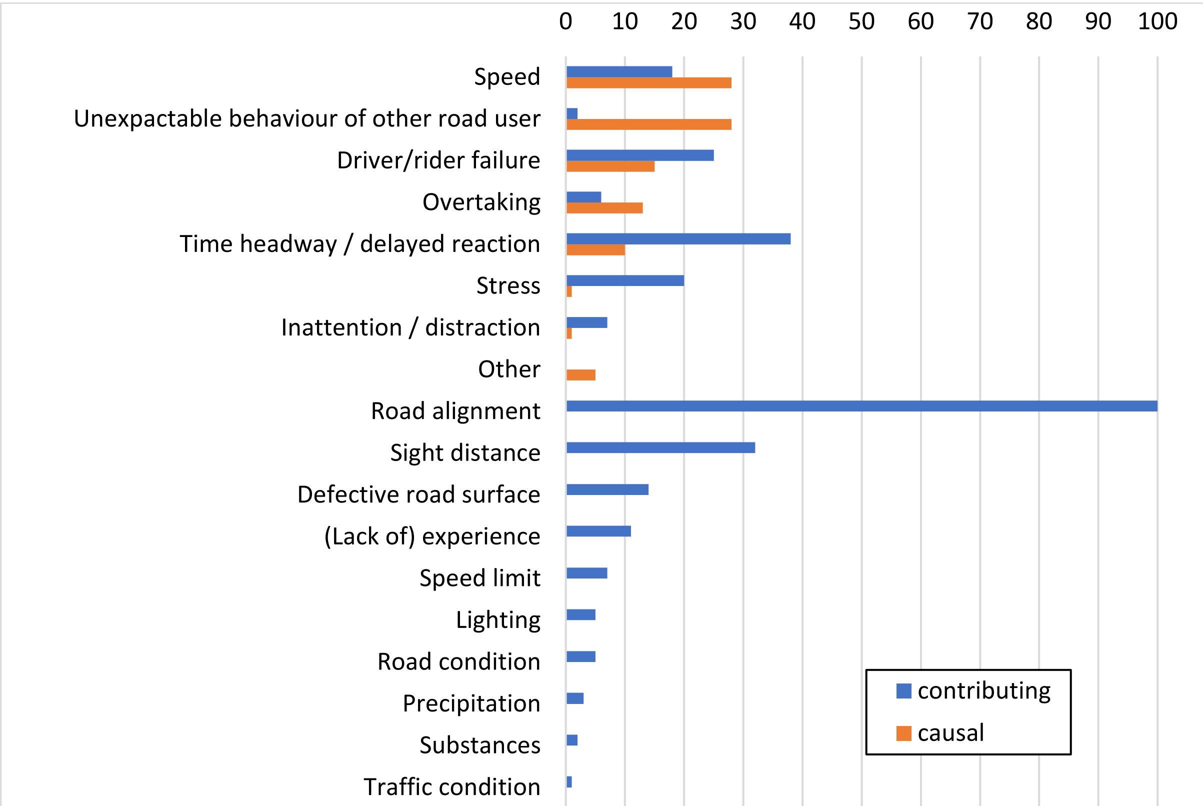


*Figure1 Number of causal and contributing factors in motorcycle crashes in Austria*

## 3.2. “Speed”: Three ways of being too fast

Crash statistics, if they provide information on the cause of an accident, typically include either one or two items – sometimes also called factors – related to speed. The typical cases are “excessive speed” and “inappropriate speed”. Excessive speed is normally considered to mean having driven above the local speed limit. Inappropriate speed relates to regulations in many countries (e.g. §20 (1) of the Austrian Road Traffic Act) which oblige drivers to drive in accordance with the local circumstances, visibility range and properties of the vehicle and load. In the case of motorcycles, there is a third factor, which probably also exists for cars, but is much more crucial for PTWs, namely roll angle. According to Spiegel (2012), there is natural limit which is common for humans and other species that limits roll angles to about 20 degrees. This limit can be exceeded, but higher roll angles require training.

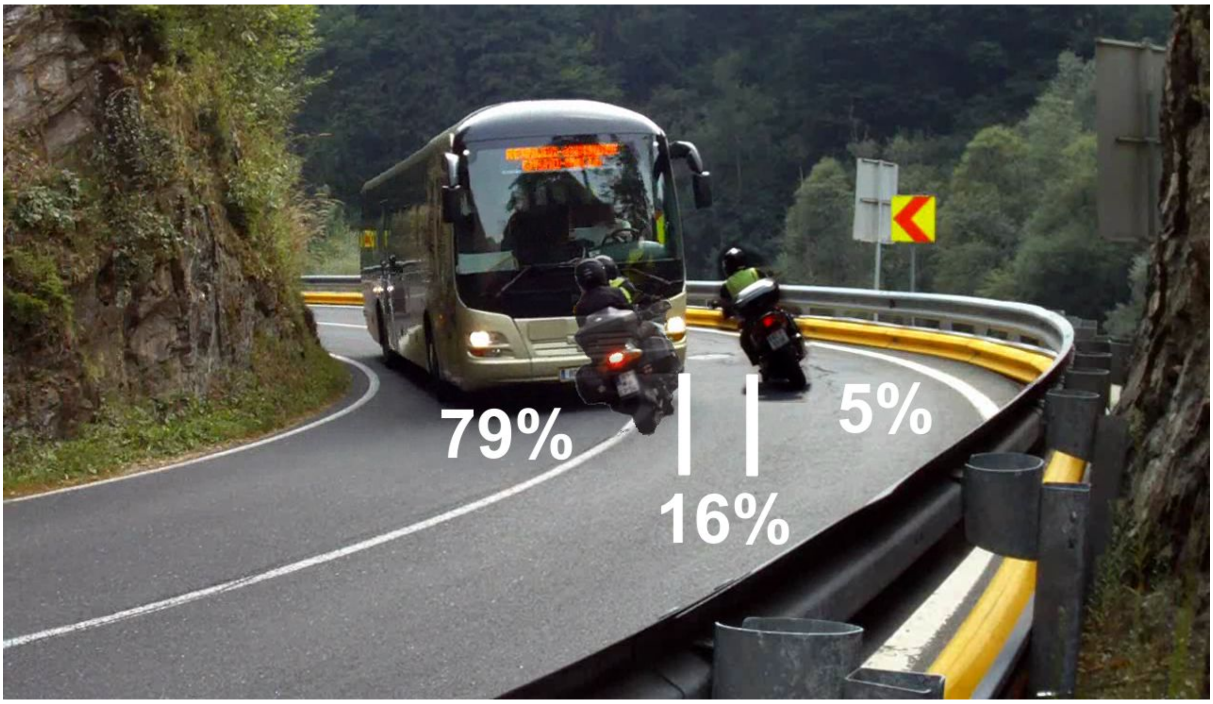


*Figure 2 Percentage distribution of driving lines in left curves (both riders and the bus in their original positions)*

This paper pursues the consequences of previous research (Winkelbauer et al, 2014), which was presented at the 2014 ifz conference (Winkelbauer, 2014). This research had analysed the trajectories of PTW riders in left-hand curves, some with poor forward visibility. According to the results of the study, four out of five riders would, without performing a swerving manoeuvre, fit between the A-pillars of an oncoming bus (Figure 2). While one would expect plenty of head-on collisions, they actually make up a relatively small share of collisions in left-hand curves. Running off to the right is far more frequent. Considering that about half of the riders who collide with guardrails hit them in an upright position whilst still sitting on their bikes (de Craen, 2011), there must be a different mechanism. The traditional cliché of inappropriate speed explains when a rider runs off the road or into a guardrail after overestimating the local level of friction or exceeding the technical limit of the motorcycle’s roll angle. However, there must be another kind of ‘inappropriate’ to explain such an ‘upright crash’.

Previous work at KFV has concluded that roll angle phobia or lean angle phobia – the terms are a direct translation of the German term *Schräglagenangst* which does not appear to exist in English[1] – delivers a potential explanation.

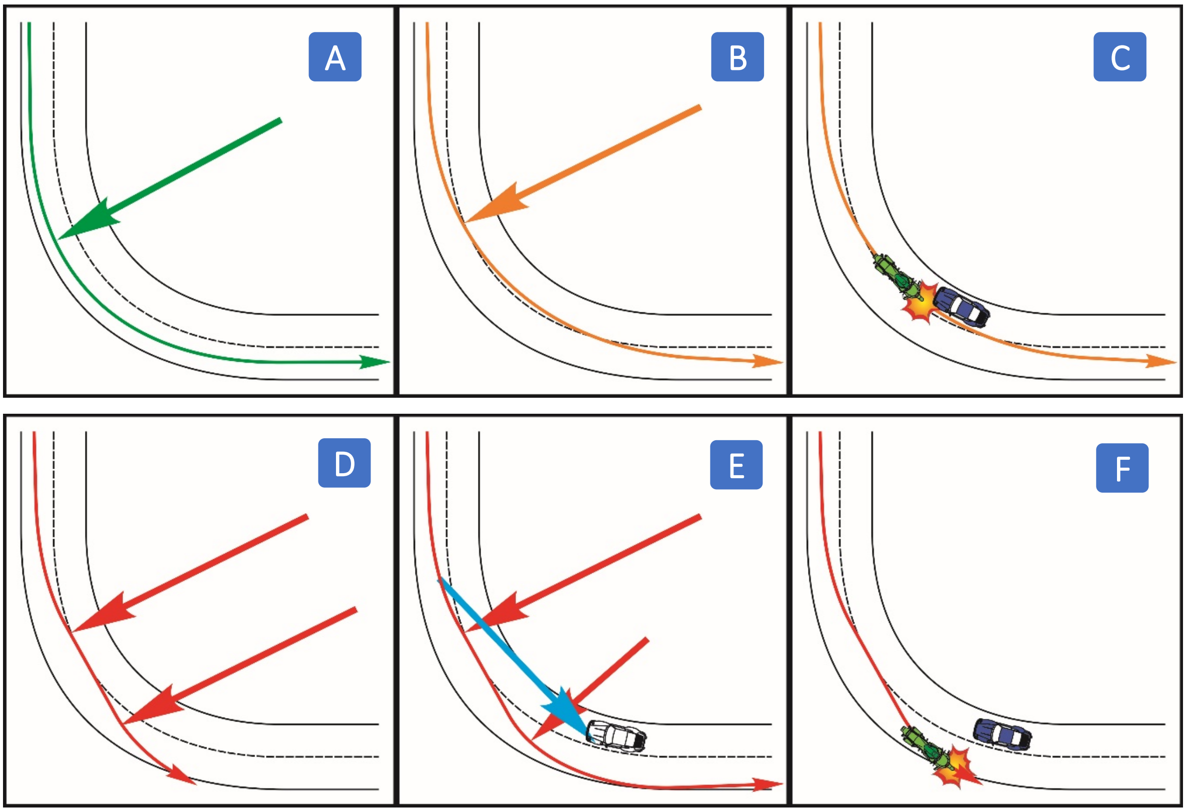


*Figure 3 Variants of trajectories in left hand curves*

A safe journey through a curve would probably start far right on the road; the rider would stay within the right third of his/her lane until there was sufficient visibility to the oncoming traffic to turn towards the centre of that lane (Figure 3A, green line). The safe trajectory would imply a certain curve radius, which – with respect to speed – requires a certain maximum roll angle. Of course, the "system motorcycle" is much more complicated, but a simple equation serves to provide a rough estimate of the relation between roll angle, curve radius and speed:

*Equation 1* $$\varphi = arctan\frac{v^2}{R*g}$$

Wherein:
- v speed
- R curve radius
- g acceleration of gravity
- φ roll angle

[1] At least Google can't find them, except for one single hit at http://www.apriliaforum.com/forums/showthread.php?61010-Lean-Angle-Phobia (retrieved 2018 07 26)

A safe rider would never lean his/her motorcycle or body beyond or even close to the centre line. Nevertheless, a majority of riders does so. This results in a larger radius, which, at the same roll angle allows for higher speed (Figure 3B, amber line). In a simple conclusion, a head-on collision (Figure 3C) would be the result, but – at least in Austria – only one in 50 collisions involving a motorcycle is this type of crash. A majority of riders obviously manage to swerve around oncoming vehicles. But this manoeuvre takes them closer to the outer edge of the curve. Staying on the track at the same curve radius (Figure 3D) is now impossible. A lower curve radius (Figure 3E) is required, which can be achieved by either increasing the roll angle or with a constant roll angle at lower speed. A rider who misses the chance of reducing speed during the swerving manoeuvre might have to go beyond his/her personal limit for roll angles and will most likely be unable to do so. This might then result in a collision with the guardrail in an upright position or a run-off-the-road crash without no skid or scratch marks (Figure 3F). One in six collisions involving a motorcycle is a run-off to the right crash in a left-hand curve; such collisions are eight times more common than head-on collisions in curves.

## 3.3. Research Questions

At the first glance, there appears to be one simple preventive measure: improving riders' roll angle tolerance. Unfortunately, riders might then also use their improved skills and still travel through curves at their maximum roll angle. Consequently, the same crashes would happen, but at a higher speed. Another option would be to teach riders to increase their roll angle temporarily through a short but heavy push to the inner end of the steering bar. This is a very good idea in theory, but in practice it is very difficult to overcome reflex reactions. More research on roll angle phobia would be another option, but this would require further basic knowledge, namely:

What roll angles do riders achieve?

Another important goal is to develop effective countermeasures. The pilot study mentioned above found promising approaches but did not deliver statistical evidence. Hence, a comprehensive study was needed to answer the question:

Do road markings effectively change riders' trajectories through left-hand curves with short visibility range for the better?

## 3.4. Hypothesis

In order to address the first question, the videos and freeze frames used for previous research (Winkelbauer & Bagar, 2013) were reused. It was suggested that – according to Spiegel's theories, a large majority of riders would typically travel at a maximum roll angle of 20 degrees. At a peak frequency of 20 to 22 degrees, the distribution of roll angles was expected to cut off and continue with trained riders at a much lower frequency, as shown in Figure 4.

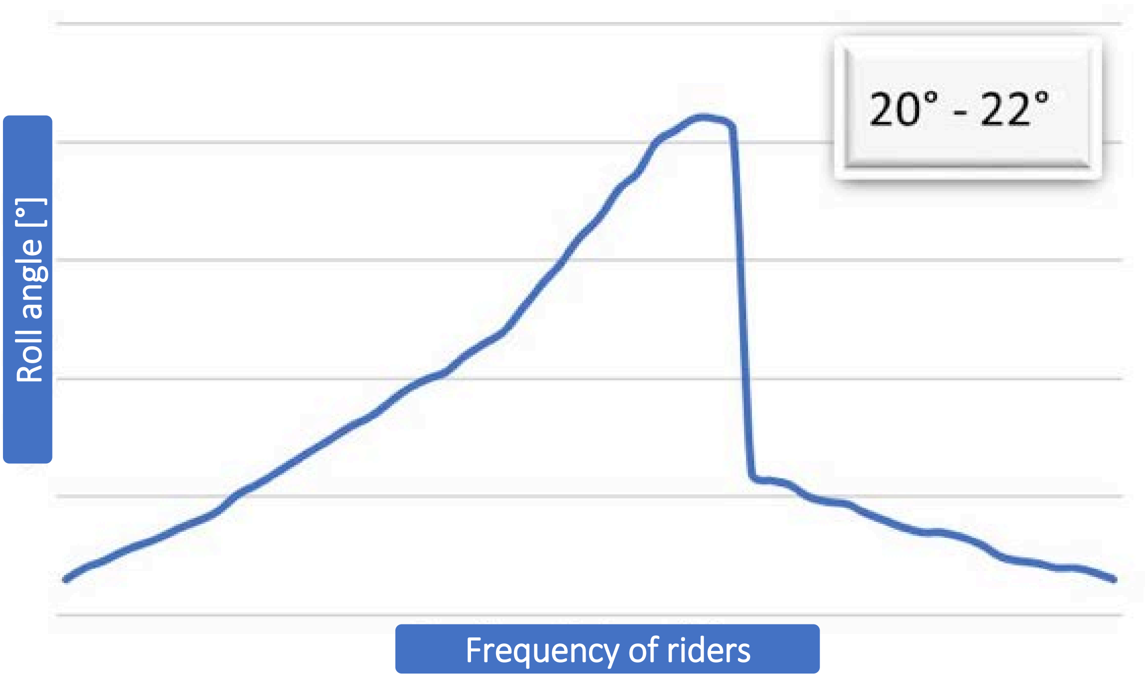


*Figure 4 Assumed distribution of roll angles of motorcyclist*

Concerning the second research question, it was expected – based on the results of the pilot – that most would choose trajectories as proposed by the road markings, i.e. they would avoid running over them.

# 4 Methodology

## 4.1. Roll angles

No empirical studies on the roll angles typically achieved by riders could be found. However, videos were available which had been used to measure lane position. From these videos, which were initially shot to demonstrate the behaviour of participants in an on-road safety training course[2], numerous freeze frames were extracted. These freeze frames were used to measure roll angles. A very simple "apparatus" was used, consisting simply of a piece of transparent film with a compass rose printed on it, which was fixed to the screen with a piece of adhesive tape (Figure 5).

[2] http://www.varahannes.at/tagestraining.htm (retrieved 2018 07 26)

*Figure 5 Computer screen with compass rose*

The video material included footage from two different left-hand curves, both located along the B99 Katschberg Straße in the Liesertal in Carinthia, a curvy section of road north of the town of Spittal/Drau. The cameras had been mounted on a signpost. They were not visible to motorcyclists to avoid distraction or any biased behaviour. A total of 295 freeze frames were included in the study. The participants in the training courses were only included with their first ride, further training rides and rides by the trainer were excluded (68 trips) along with all rides on wet road surface (14), which resulted in a final total of 213 observations. In addition to roll angle, other variables were also captured for later analysis, namely: lane position, type of motorcycle and riding style, i.e. the position of the rider on the motorcycle in four groups (Bayer, 1986).

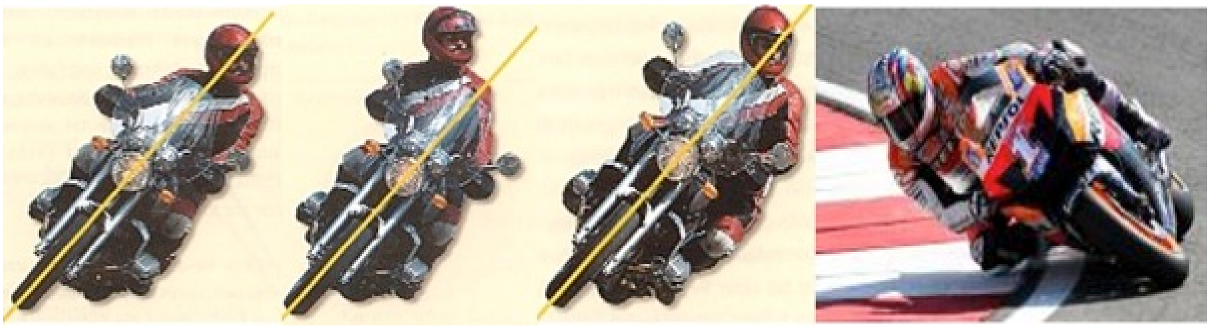

*Figure 6 Roll angles of motorcycle driving (Quelle: http://www.motorradfahrer-lev.de/index.php?article_id=113)*

- Laying: Motorcycle and rider form a line. With this technique, the direction of travel can be corrected quickly, and the posture requires less strength.

- Press: The angle of the motorbike is higher than that of the driver. This cornering technique originates from off-road sport and is used mainly for tight turns, hairpin bends or evasive manoeuvres.

- Hang: The driver's angle is higher than that of the motorcycle. At the same cornering speed, this technique requires less roll angles, rather than force (Thomson, 2011).

- Hanging off: The highest possible inclination. (Racetrack: the knee is used to scrape the roadway, by some drivers as a "third pillar") (Kohls, 2011)

## 4.2. Effectiveness of road markings

This research was planned as a before-and-after study. The budget was calculated to allow the research team to select nine curves, observe the behaviour of 500 motorcyclists in each curve (both before and after the intervention) and include an interview survey with 200 riders.

The underlying principle of the intervention is that riders – at least in Austria – are reluctant to ride over road markings because they are taught that they should avoid any potentially slippery areas of the road, such as manhole covers, bitumen repairs or road markings. Although road markings have by law had to provide as much friction as the surrounding road surface for more than two decades, this advice is still given in driving schools and is still present in riders' brains.

The first step was to find partners. The road administration organizations in Carinthia, Lower Austria and Burgenland, three of nine regions in Austria, agreed to support the study. The second step was to select the curves. First priority was given to high-risk sites where at least three severe motorcycle crashes had occurred within the last three years. Some sites had to be excluded, e.g. because there were no centre lines, repaired cracks were present on the best trajectory or there was negative crossfall. The third step involved the selection of the design of the road markings. One of the project partners proposed that the study should not be restricted to the elliptic design (see Figure 8A) which was suggested by the results of the pilot. He proposed adopting the "psychological brake" (Figure 7, referred to later in this paper as the "bar design), which was developed in Austria in the 1970s (Schützenhöfer, 1982 cited in Kaba&Klemenjak, 1994). This design had to be adapted slightly, a minimum area without road markings had to remain as the "channel" for riders. In addition, the left and right bars would not be equal in length (see Figure 8B) if the trajectory fits generally accepted recommendations (Angermann, 2018)

*Figure 7 Psychological brake*

*Figure 8 Shape of road markings; A: elliptic design, B: psychological brake (bar design)*

A key question concerned the type of material to be used, since the road markings would presumably have to be removed after the study. As it transpired, this did not happen because the results were good and no complaints were received from the public. It also had to be ensured that the risk of any rider sustaining any harm due to the road markings was reduced to the absolute minimum. Safety was paramount to avoid any negative impacts also for the project partners within the road administration organizations. Hence, the best material was just good enough. Good experience had been had in Carinthia with Stamark 380 sheet material from 3M, which had withstood winter services for at least three years during the early pilot tests. A big advantage of this material is the lack of any drying time. After application, the respective lane can be reopened immediately, which is a big advantage on busy, mountain roads. However, subsequent experience showed that this material is not suitable for motorcycle routes with a high share of heavy goods vehicles. On such roads, the sheet material remains in place only for a few weeks.

No systematic approach was used to select the design used in each of the curves: this decision was left to the respective local road administration organization. In the end, three curves were equipped with the elliptic design, five curves with the bar design, of which one was a hairpin bend. One curve could not be included due to a massive rockfall after the preparatory phase. Unfortunately, this was also the most interesting curve, as it had been included in both the pilot study and the roll-angle study. The hairpin bend (along B91, Loiblpass) was not included in the general assessment for reasons which will be outlined in the Results chapter below. Figure 9 provides an overview of the test sites and the respective design of the road marking used.

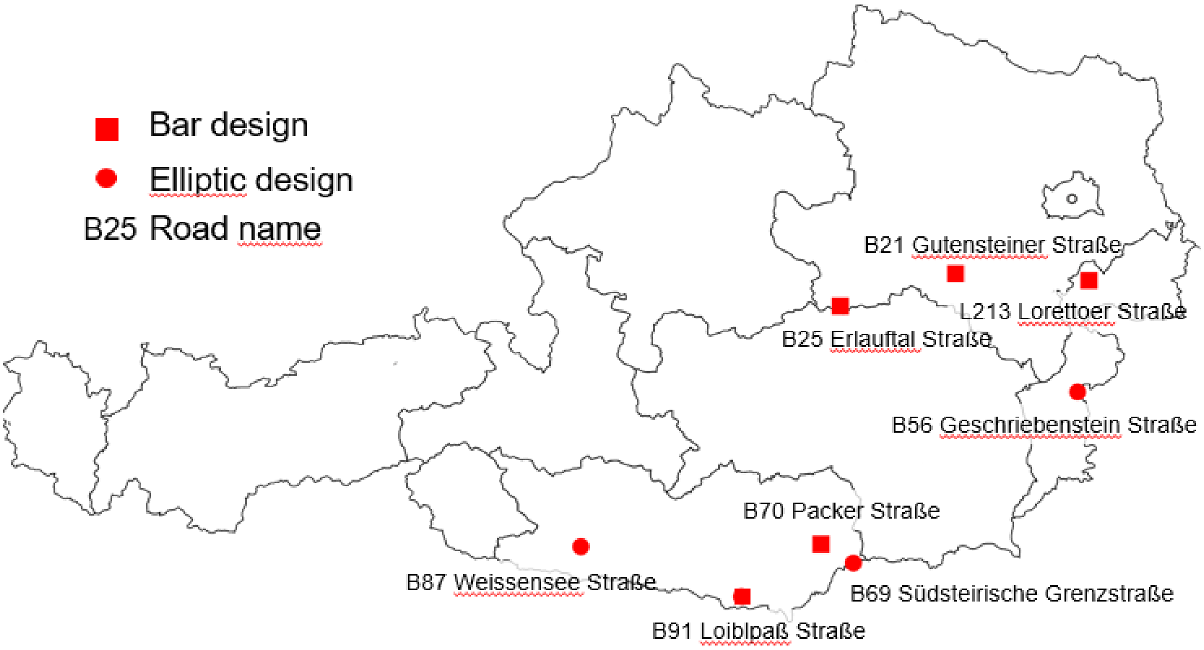


*Figure 9 Location of the test sites*

The field work was supported by video observation. The initial idea of doing all analysis using automatic image processing had to be revised due to issues with the video resolution. The image processing allowed us to isolate the episodes with a motorcycle present (which saved a lot of time), but lane position, type of motorcycle and presence of a pillion passenger had to be annotated manually using a graphical user interface developed specifically for this purpose. The cameras were placed some metres away from the shoulder on the inner side of the curve. They were fitted with sufficient memory storage for a full day and an external accumulator pack to avoid any need to touch the camera during the day and, hence, any change in the camera's field of vision. Three cameras were mounted in each curve, one at the beginning of the curve, one at the vertex and one at the exit. The cameras were left at a curve for one day, which sufficed in most cases to achieve the goal of at least 500 observations.

*Table 1 Number of observations by design and phase of observation*

| | before | after | total |
|---|---|---|---|
| elliptic design | 1,546 | 4,581 | 6,127 |
| bar design | 4,052 | 6,987 | 8,039 |
| bars 1 side only | 598 | 6,165 | 3,763 |
| no intervention | 824 | - | 824 |
| total | 7,020 | 11,733 | 18,753 |

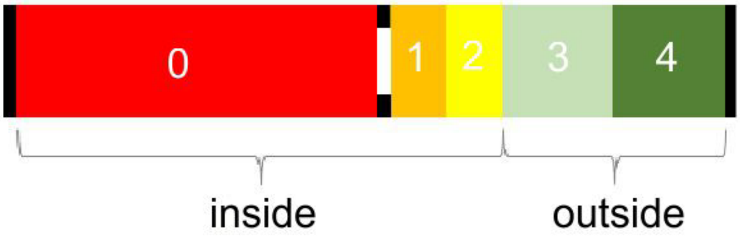


*Figure 10 Segments for classification of trajectories*

The trajectories were classified as indicated in Figure 10. The colour selection is based on traffic light colours: red indicates the prohibited area in the opposite lane, green communicates that this is the best area, at least at the beginning and the vertex of a curve.

The video observation was accompanied by a survey among motorcyclists to investigate their opinions and acceptance of the two types of road markings. Respondents were asked about their own lane position when passing the road markings as well as the meaning, usefulness and effectiveness of these markings. 106 riders who had passed the road markings prior to the interview and 123 who had not seen them were interviewed at two restaurants close to one of the curves that are popular stops for motorcyclists.

# 5 Results

## 5.1. Roll angles

The results of the survey are shown for both curves together. Differences in the two curves have been statistically tested without detecting any significance.

*Table 2 Number of observations by type of motorcycle*

| Motorradtyp | Anzahl |
|---|---|
| Chopper | 19 |
| Cross | 1 |
| Enduro | 69 |
| Goldwing | 1 |
| Moped | 2 |
| Naked Bike | 42 |
| Roller | 12 |
| Supermoto | 17 |
| Supersportler | 24 |
| Tourer | 26 |

The analysis of the freeze frames of 213 motorcyclists (Table 2) shows that Enduro riders were the most frequent. Figure 11 shows that the most frequently observed roll angles were 24 to 30 degrees, with another peak observed at 35 degrees.

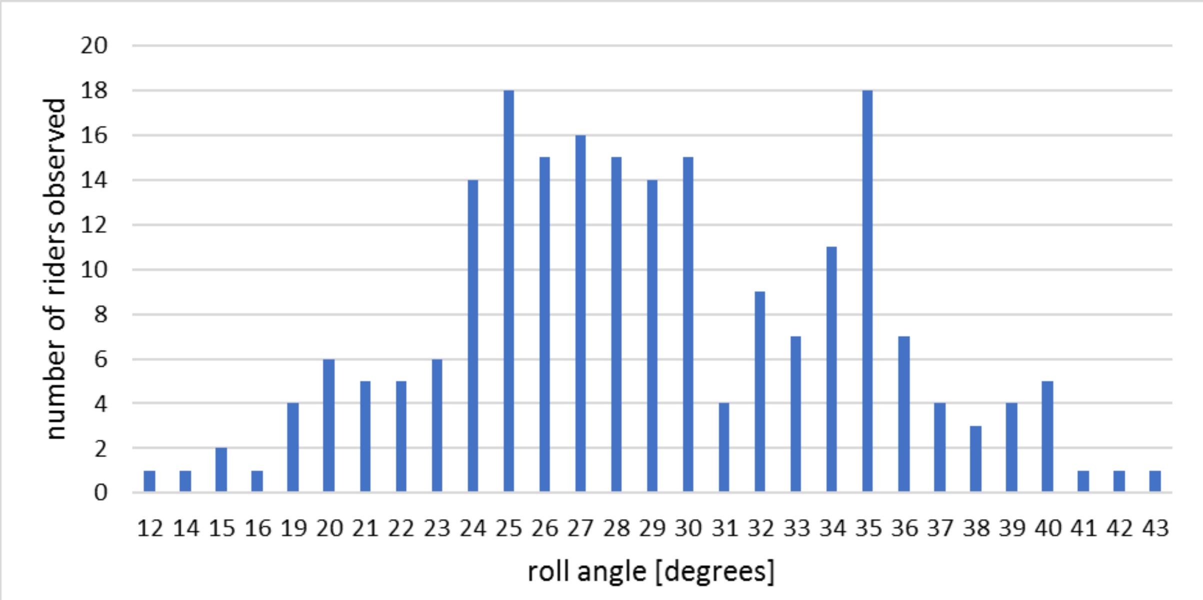


*Figure 11 Number of riders observed by roll angle (n=213)*

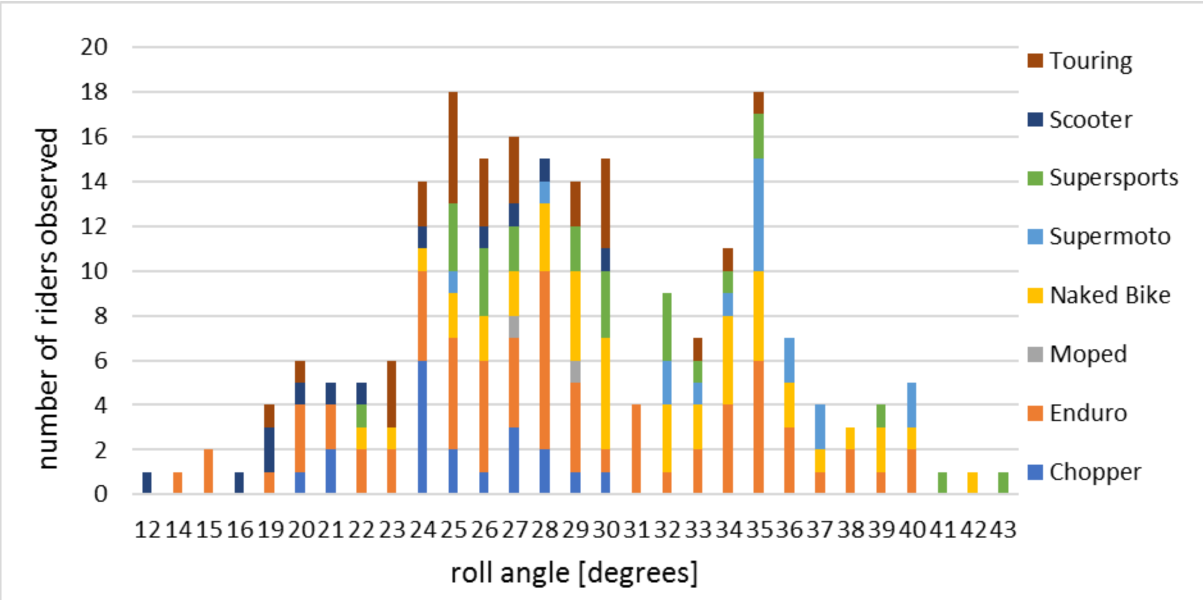


*Figure 12 Frequency of roll angles by type of motorcycle (n=213)*

It seems that the riders of some types of motorcycle prefer the roll angles that common sense dictates (Figure 12): Particularly high roll angles were preferred by supersports and supermoto riders. Riders of naked bikes had a tendency for higher roll angles, while scooter and chopper riders were predominantly found to use low roll angles. Enduro and tourer riders are found across the full bandwidth of roll angles.

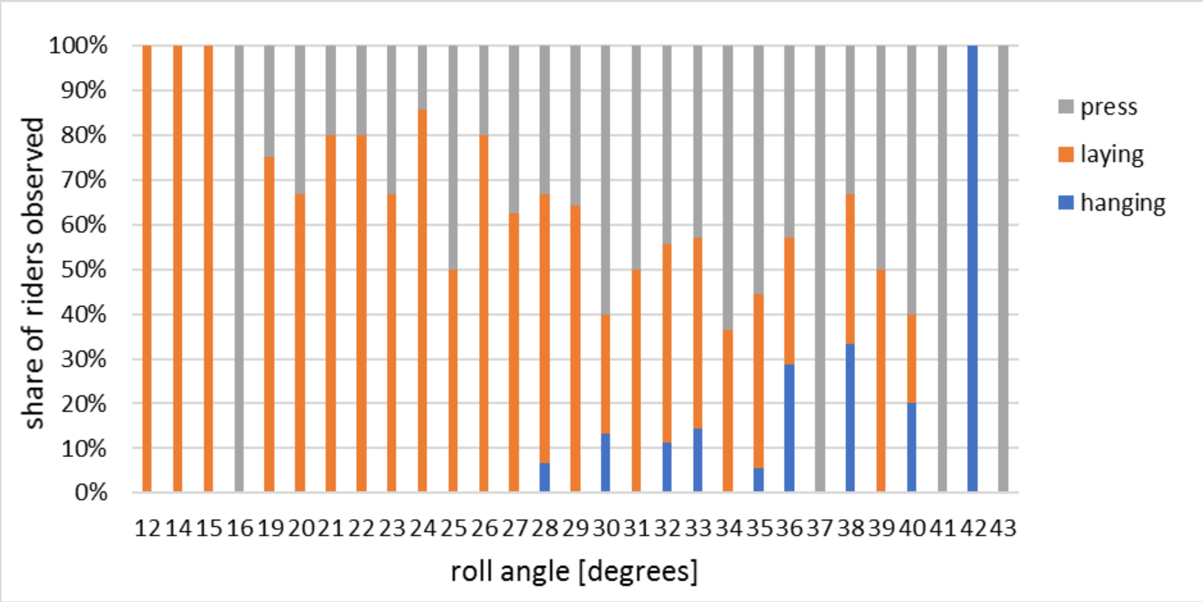


*Figure 13 Curve riding style by Frequency of roll angles (n=213)*

Typically, hanging is a riding style which is associated with high speed and high roll angles. Hence, the result for hanging in Figure 13 is as expected. Pressing increases the roll angle of a vehicle, which means that a pressing rider rides at lower speed than a laying rider at the same roll angle. The relatively high share of pressing is presumably an indication of the difficulty of riding the two particular curves.

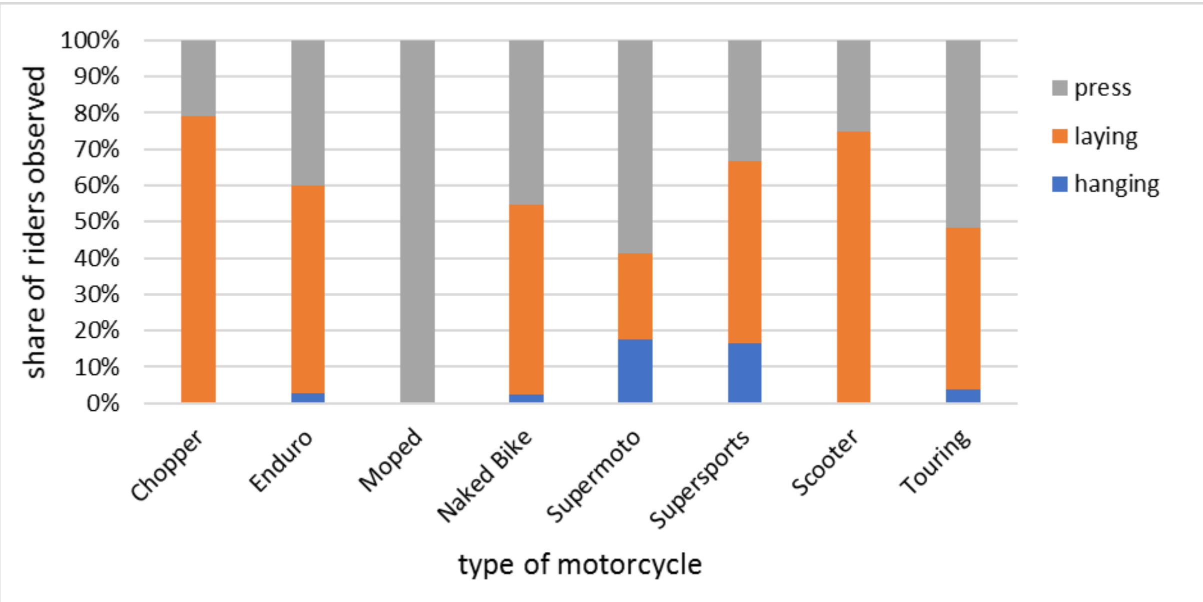


*Figure 14 Curve riding style by type of motorcycle (n=213)*

It is generally accepted that hanging as a riding style should not be used on public roads. Hanging did not appear frequently (Figure 14) and was used by those riders who would have been most expected to do so (i.e. supersports and supermoto riders).

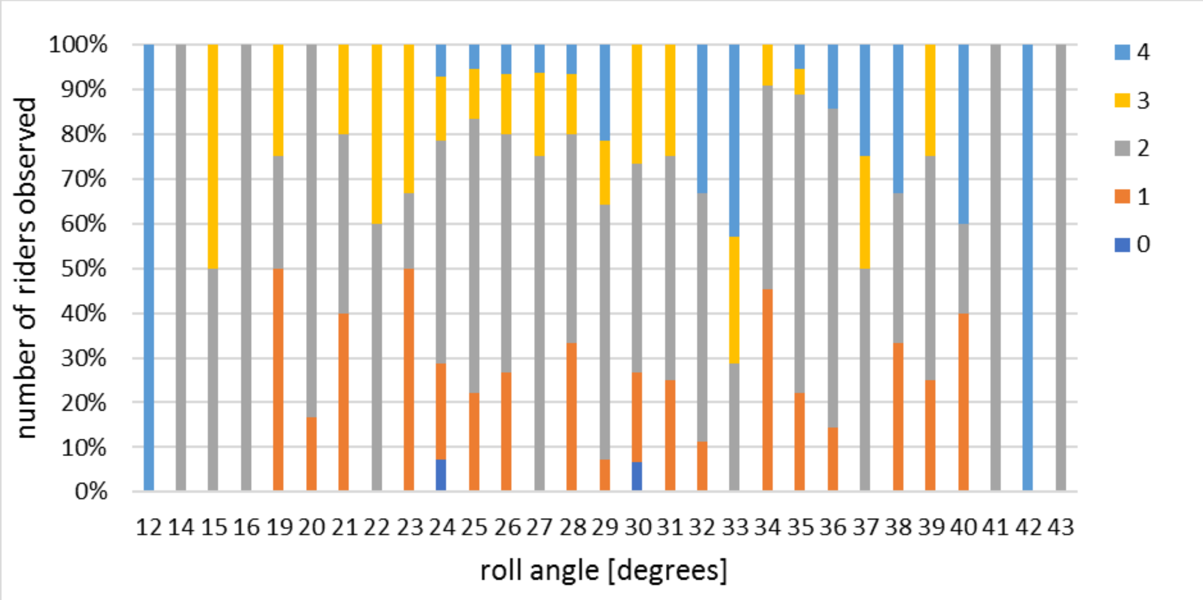


*Figure 15 Frequency of roll angles by lane position at the vertex (n=213)*

Figure 15 shows that the majority of riders prefer the centre of their own lane. There is a tendency for riding at an increased roll angle to be associated with the selection of a trajectory on the outside of the curve.

## 5.2. Observation of lane positions

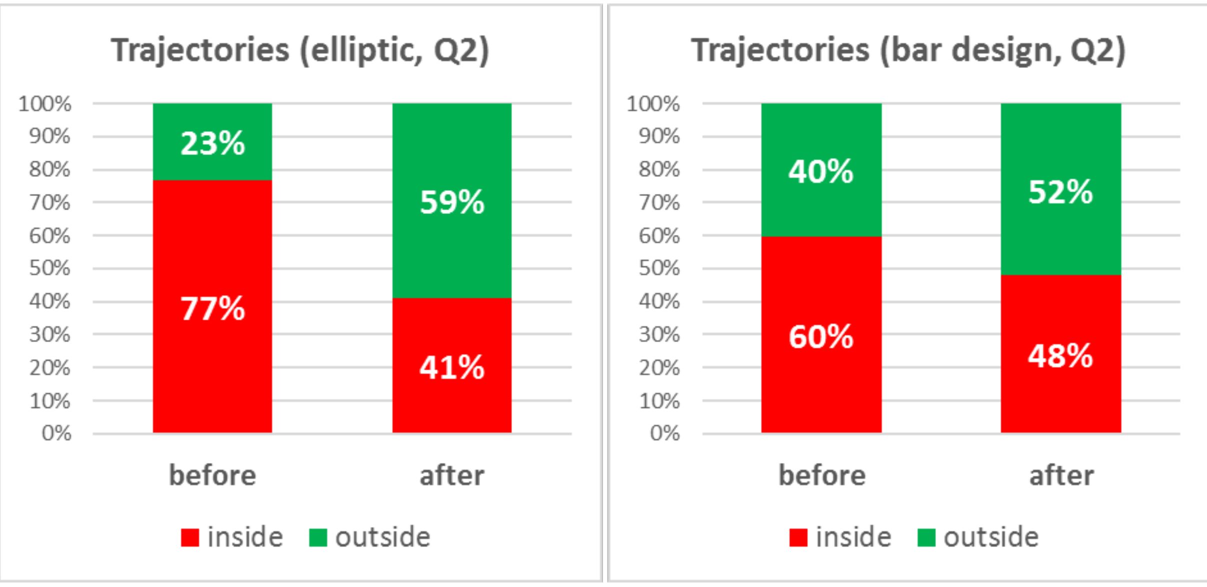


*Figure 16 Distribution of trajectories, overall results at the vertex, before and after, for elliptic and bar design*

Figure 16 displays the overall and most important result of the study. This result is based on seven "regular" curves; the hairpin was not included, and no observation could be carried out at one curve due to a massive rockfall. There are strong decreases in the number of riders who choose a trajectory close to the centre of the road for both road marking designs after the intervention. While the elliptic design seems to have the stronger impact, all differences displayed below were statistically significant.

Figure 17 shows the results of all 7 curves added up, with more details for the segments. The share of riders observed in segments 0, 1 and 2 decreased after the intervention. More riders chose to ride in the centre of their lane as proposed by the road markings. The share of riders in segment 4 did not change.

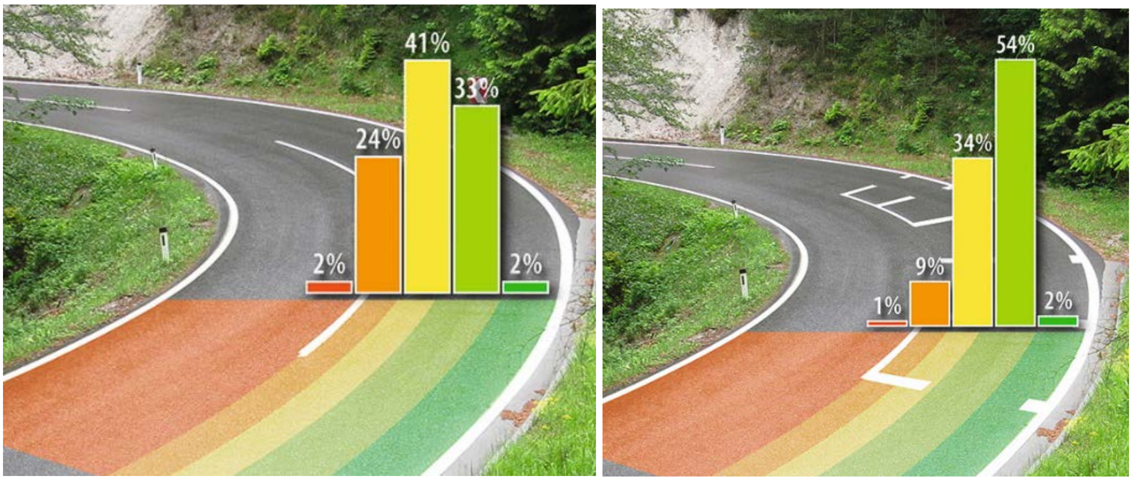


*Figure 17 Distribution of trajectories, overall results at the vertex, before and after, all 7 curves (symbolic background)*

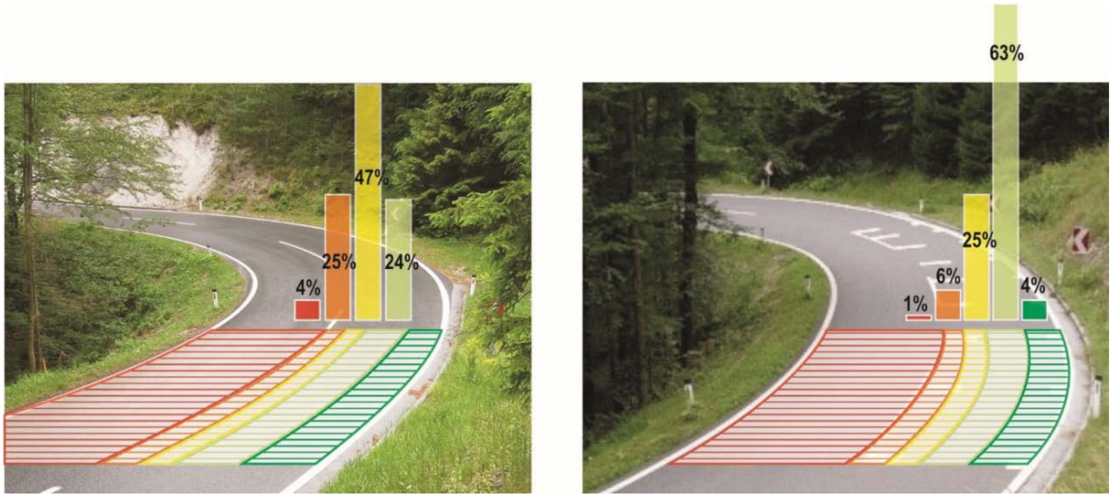


*Figure 18 Distribution of trajectories, overall results at the vertex, before and after, best curve (symbolic background)*

The best results (Figure 18) were obtained for a curve along the B87, Weißensee Road, where the previous (right-hand) curve was also fitted with elliptic design road markings in order to avoid riders being captured on the wrong side of the road markings. The Weißensee Road is a freshly surfaced, beautiful, harmonic road, which makes it very popular with motorcyclists. It could be argued that the sharp right-hand curve before the test curve was the reason for many riders to use the opposite lane, a phenomenon which almost disappeared in the after-period. There were even superior results for segment 4 (dark green).

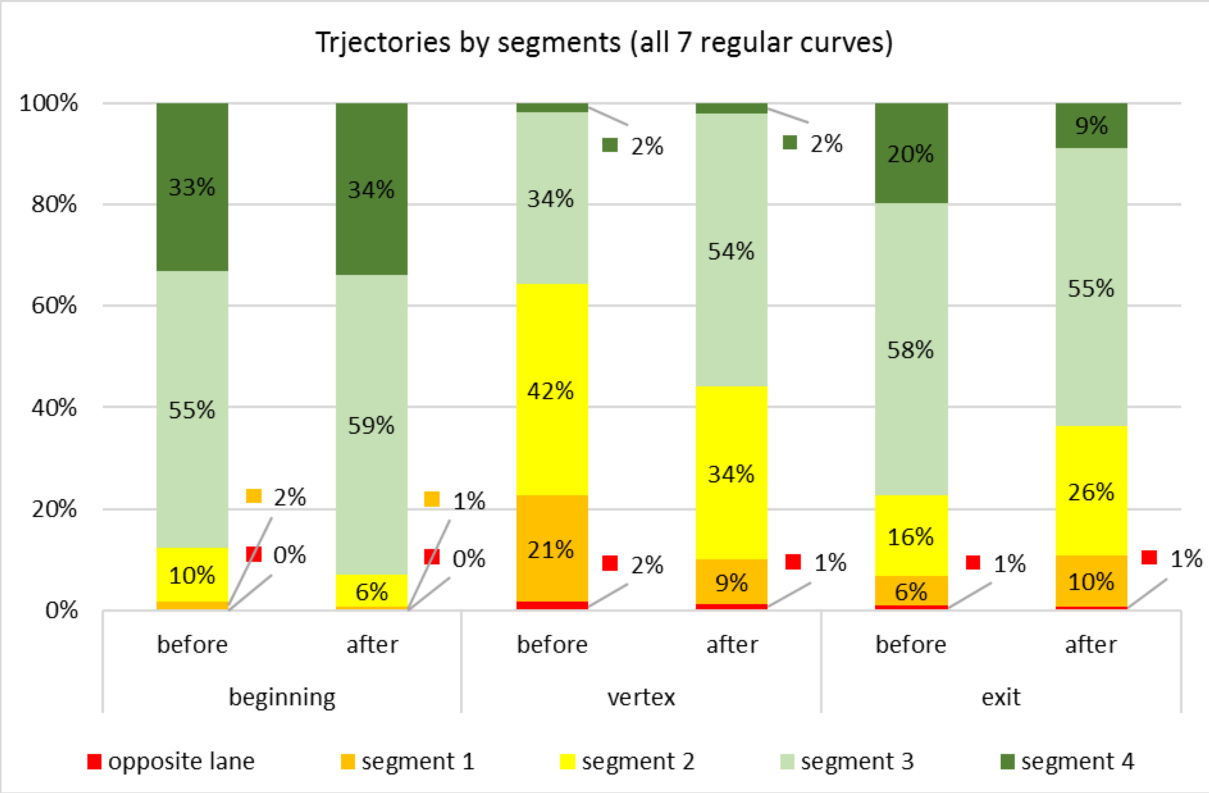


*Figure 19 Distribution of trajectories, overall results, all sections, before and after*

Figure 19 also shows the results for the beginning and the exit. Based on common agreement on how trajectories in curves should be chosen, the intervention causes a change for the better in these sections as well. There is a slight shift to the right at the beginning of the curve and a slight shift to left at the exit. Further analysis indicated that although it performed better at the vertex, the elliptic design has less influence on trajectories at the beginning and end of a curve. For the bar design, the opposite was the case.

The analysis of driving speed was limited to cases where the automatic video analysis could detect the same vehicle at the beginning, the vertex and the exit of a curve. Essentially, there were no significant differences before and after the intervention either for the elliptic or for the bar design.

## 5.3. Interview survey

All riders who participated in the interview survey (n=229) thought that the bar design had an impact on the behaviour of riders in the curve. 74% of the interviewees also thought that the elliptic design had an impact. Of the riders who had driven past the road markings (n=106), 97% of those who had passed the bar design prior to the interview (n=29) did not recall having done so without a reminder. 61 % of riders who had passed the elliptic markings (n=77) did not recall them, which means that 39% did – compared to 3% for the bar design. The bar design was considered to provide better intuitive advice.

Some of the riders were somewhat surprised when they saw the elliptic markings, but also said that their inclination not to ride over the markings was stronger with the elliptic than with the bar design. A huge majority of riders gave positive overall feedback, saying that it makes sense to use these markings and that they considered them effective in influencing riders' trajectories. Most riders expected a positive effect on motorcycle safety.

## 5.4. Hairpin bend

The hairpin bend observed in the study was special not just because it is a hairpin. There is a sharp right-hand curve just before the hairpin in which riders approach the hairpin quite close to or even beyond the centre line. Further, the centre line is barely visible (i.e. almost faded). Bars were applied only on the left side of the lane. Finally, there was a strong bias in the sample. The after-observation took place during a huge Harley-Davidson rider convention in Faak/See, a location just a few kilometres away from the observed hairpin. Chopper riders were thus by far the most frequent among the motorcycle riders passing by the test site.

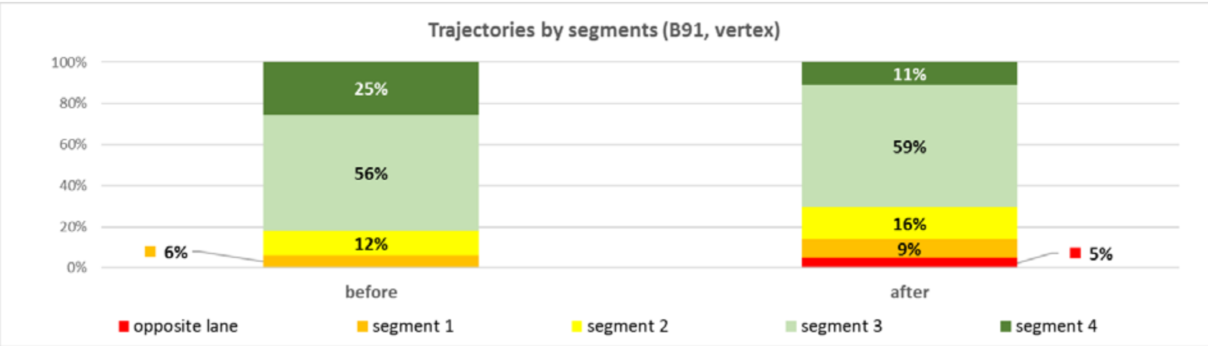


*Figure 20 Distribution of trajectories, hairpin curve, vertex, before and after*

The hairpin was the only curve in which the number of riders in the "forbidden area" increased after the intervention.

# 6 Conclusions

Based on the results, the hypothesis about roll angles turned out to be completely wrong. The actual roll angles used by motorcycle riders are higher and much more evenly distributed over a large bandwidth from about 20 to 40 degrees. Most motorcyclists chose a roll angle between 24 and 30 degrees. A second peak in frequency was found at 35 degrees. There were differences between riders of different types of motorcycles. In some cases, riders fully fit their stereotype, like supersports and supermoto riders choosing higher roll angles or scooter and chopper riders typically choosing low roll angles. Riders of other types of motorcycles can be found more or less across the whole bandwidth of roll angles.

Similarly, riders stuck to their stereotypes in the study on road markings. The results for the hairpin bend were so heavily biased by the share of chopper riders that is unclear if they deliver information about the curve or about chopper riders. This was the main reason why the hairpin was finally excluded from the analysis with the other curves. Including a hairpin in the study was an experiment and indicated that a lot more research is needed. Hairpin bends are challenging for unexperienced riders and are probably a greater challenge on right-hand rather than left-hand curves. In addition to the data acquisition on the research question, it was observed that the bar design markings were a challenge for riders travelling in the opposite direction.

For the major part of the study including seven curves, the hypothesis turned out to be perfectly correct. Trajectories were significantly altered by the application of road markings exactly as had been expected at all three sections of the curves. The elliptic design proved to be more effective. The bar design was better in altering the trajectory at the beginning and exit of a curve as well and performed slightly better from a public acceptance perspective. Hence, the elliptic design is probably more favourable on routes with lower frequencies and real problems, while the bar design might be more suitable for more heavily frequented motorcycle routes and stronger public impact.

Differences between the riders of diverse types of motorcycles are also evident in their riding styles in curves. Again, if there is a stereotype, the riders fit it. Supermoto and supersports riders are most frequent in the "hanging" category; hanging is associated with higher roll angles. Chopper and scooter riders typically ride their bikes "laying" into curves.

Experience might be another issue. It can be assumed that very experienced riders will achieve higher roll angles. It can also be assumed that experienced riders ride to a larger extent further to the right. In the study, higher roll angles appear to be associated with lane positions further to the right.

Despite the significance of the results, their applicability is limited: The study included left-hand curves in mountainous regions with a high share of motorcycles but little heavy traffic. All curves were high-risk sites for motorcycle crashes, they all had a high share of curve cutting and were all located on motorcycle routes. Hence, painting bars or ellipses on each and every curve is not proposed. Instead, the results of the study recommend using road markings as an intervention at relevant high-risk sites.

The roll angle study, although including more than 200 observations, should be considered a pilot study. It only covered two curves, both of which were left-hand curves on the same road in a mountainous region and had a short visibility range, a crossfall of about 3 degrees, a radius of about 30 metres, guard rails at the right shoulder and many large chevron signs. The only conclusion that can be drawn from this study is that either Spiegel's hypothesis on lean angles is not fully correct or most riders have acquired more to roll angle tolerance, either through training or experience. Training appears unlikely as a reason given that only about 2% of the Austrian population goes through anything that can be considered skill-oriented advanced rider training each year.

If typical roll angles are well-known, recommendations for curve speed could be calculated. Section-based speed limits, in particular those that are valid only for motorcycles, are very unpopular among riders and make little sense if curve speeds are much lower than the speed limits (which now can be estimated given what we know about typical lean angles). Road signs could inform riders of the appropriate speed at low and high roll angles – in the same way rally drivers get information from their codriver. This does not mean that riders should meticulously observe their speedometer, but they could gain experience about how fast they can go through a curve with respect to the recommended speed. Of course, the impact of such recommendations would have to be evaluated carefully.

Neither of the surveys presented in this paper investigate the extent to which the observations are related to the vehicle or to the predominant riders of particular types of motorcycles – either for roll angles or for lane positions. In other (Bernd Spiegel's) words, we did not distinguish between the upper and the lower half of the motorcycle; the data would not support such analysis. Hence, more research is needed that includes more curves, more riders, more variations of all properties of curves as well as more road markings. In the case of the latter, accident analysis will have to be done when data for a sufficient after-period is available.

# 7 Outlook

Even before the end of the study, six curves on the Großglockner Hochalpenstraße were fitted with markings in elliptic design. An evaluation study investigating trajectories is currently going on, the results of which will be included in the oral presentation. Eleven curves in Styria were fitted with bar design markings. All available information was provided to the road administration organization in Luxembourg, which in the meantime has initiated a pilot on a 6 km stretch of the N25 near Kautenbach. The circumstances there are unique; Luxembourg has a huge share of non-resident riders among motorcycle crash victims. First results from this pilot should also be available for the oral presentation of this paper. In Slovenia, a motorcycle route with frequent illegal street racing events was also fitted with road markings along the centre line. While some of these locations will be subject to accident analysis, no data is available as yet due to the short after-period. No severe crashes have been reported so far at the seven curves in Austria, despite the fact that all seven locations had been high-risk sites prior to the intervention.

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# 10 Figures

# Tables