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Seeing the road, shaping the path: drivers' gaze strategies and lateral control on curves

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A R T I C L E I N F O

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A B S T R A C T

Drivers adopt different gaze strategies to manage steering through curves. However, most research has examined only some of these strategies separately, rather than analysing how drivers select among them and how these choices affect vehicle control. This study explores how road- and driver-related factors influence gaze strategy choices during horizontal curve negotiation in a simulator, and how the chosen strategy relates to lateral control performance. Thirty licensed drivers operated a fixed-base simulator on two-lane rural roads under daytime, clear weather conditions. A factorial design included variables such as curve radius, curve direction, sight obstruction, and the presence or absence of road markings and post-mounted delineators. Eye movements were recorded, and for each curve, gaze behaviour was classified into one of four strategies: tangent point (TP), future path (FP), fixed point (FXP), and external (EX). A panel-data mixed logit model assessed how infrastructure and driver attributes influenced the likelihood of each strategy. Subsequently, linear mixed-effects models examined how gaze strategy and road-related factors affected the mean lateral position, its standard deviation, and mean speed. FP was the most prevalent strategy, while curve geometry, markings, delineators, and driver experience influenced the relative utilisation of TP, FXP, and EX. TP and FP correlated with smaller mean lateral positions and less variability, whereas FXP, especially in the presence of delineators, produced larger deviations on left-hand curves and the greatest variability. EX was more common among experienced drivers and maintained lateral stability similar to TP and FP. Gaze strategy did not significantly influence mean speed.

1. Introduction

Negotiating horizontal curves requires continuous coordination among perceived road geometry, vehicle dynamics, and lane-keeping goals. Although steering is supported by multiple information sources, visual preview of the roadway is central to anticipating curvature and timing steering inputs so that the vehicle follows the intended path. Drivers extract directional information from cues such as lane boundaries, edge lines, and roadside delineations, and use it to adjust steering and regulate speed as the curve unfolds.

Many researchers have studied drivers' gaze patterns and the strategies they use when negotiating a curve. Land and Lee (1994) found that drivers often focus on the tangent point (TP) on the inside boundary of the road (e.g., lane marking or edge of the pavement) when approaching and negotiating a curve. They observed that participants mainly relied on the TP within each curve, making a

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saccadic movement toward it about one or two seconds before acting on the steering wheel, and used this point throughout the entire curve with regular fixations. In theory, drivers can estimate the road's curvature using the TP gaze strategy, which helps them to steer smoothly (Lappi et al., 2013). Land and Furneaux (1997) argued that many drivers use the TP as a direct input for steering control; it is also the only point that does not move laterally, except when the curvature changes. Additionally, by observing the TP, the driver gains a clear view of the road beyond the curve and can therefore become aware of distant hazards.

However, not all evidence supports the TP as the sole or dominant gaze strategy. In some experiments where gaze is explicitly directed to a specified location, steering can be biased toward the direction of gaze (Robertshaw & Wilkie, 2008; Wilkie & Wann, 2002). Based on this, to follow the road's course, drivers should naturally look into the curve rather than at the roadside. However, this relationship is not invariant. Mars (2008) reported contralateral trajectory deviations when drivers were required to direct gaze to targets near the tangent point. Kountouriotis et al. (2015) likewise observed conditions in which drivers tended to steer away from eccentric fixation, which they interpreted as a compensatory response. An alternative view is that drivers direct their eyes toward the future path (FP), which is a point on the road surface where they expect their future trajectory to pass (Wann & Land, 2000). Several experimental findings support the FP strategy. Lappi et al. (2013) analysed eye movements and found that drivers' gaze often extends beyond the TP into the “far zone” of the curve, indicating that the most distant visible section of the road is an important gaze target during smooth, steady negotiation of a curve. Itkonen et al. (2015) studied drivers' gaze patterns in two conditions: one where drivers were allowed to drive normally, and another where they were instructed to look at TP when steering through a curve. Under normal driving conditions, they observed that participants' gaze patterns differed significantly from a pure TP strategy and instead aligned with fixating on waypoints along the future path of the curve.

Within the broader FP strategy, Lehtonen et al. (2012) identified a FP sub-strategy called occlusion point (OP). It is defined as the furthest visible point on the road ahead where the road disappears from view due to curvature or an obstacle. Fixating on the OP is a proactive gaze behaviour, as it allows the driver to anticipate what lies beyond the immediate bend, such as oncoming vehicles or the roadway alignment after the curve.

Wann and Land (2000) discussed that fixating on a point and observing how its angle relative to the vehicle's heading changes over time can inform the driver about road curvature. Han et al. (2019) observed that adding wall-mounted delineators along curves in tunnels can guide drivers' vision as they navigate the curve. They also found that sometimes drivers look outside the curve as a curve-negotiation gaze strategy.

Evidence is emerging that the preferred gaze strategy may depend on roadway geometry and roadside elements. For example, Kandil et al. (2010) found that when sight distance and curve radius were reduced, drivers relied more on the TP gaze strategy. In contrast, Robertshaw and Wilkie (2008) did not find significant differences in the use of the TP strategy based on curvature. Still, they did find that lane width had a substantial effect on the choice of TP strategy. Lehtonen et al. (2012) observed that drivers tended to look at the OP when approaching the curve with long sight distance. Kandil et al. (2010) also concluded that in left-hand curves, the likelihood of TP was lower compared with right-hand curves, whereas the likelihood of FP was higher. Mecheri et al. (2022) reported that, when negotiating right-hand curves, the presence of a shoulder induced gaze toward the inside of the curve (i.e., toward the TP) compared with its absence. On roads with shoulders, Mecheri et al. (2024) found that continuous edge-line markings shifted drivers' gaze, and accordingly vehicle trajectories, toward the lane centre relative to dashed edge-line markings. Driver-related factors can also affect the gaze strategy used, as previous work has found relationships between expertise and visual search (Pammer & Blink, 2018) and between knowledge and cognitive load when approaching a high-speed curve (Celic et al., 2024). However, no study examines the effect of driver-related factors on gaze strategy during curve negotiation.

Previous research has often concentrated on specific gaze strategies or individual factors, but it has not established a statistical model to predict the likelihood of employing different gaze strategies during curve negotiation. Additionally, although many studies implicitly assume that certain gaze strategies improve vehicle control, few have quantified how the dominant strategy, under particular road and driver conditions, relates to lateral position and its variability. To fill this gap, this study aims to develop a statistical model that predicts drivers' gaze strategy choices when negotiating a horizontal curve, based on factors such as curve radius,

(a) (b)

Fig. 1. (a) Driving simulator and (b) eye-tracker at the Road Safety Laboratory, Politecnico di Torino.

curve direction, sight obstruction, the presence of road markings and post-mounted delineators, and driver characteristics. Specifically, a panel-data mixed logit approach is utilised to measure how these roadway and driver-related factors influence the probability of adopting each gaze strategy during curve negotiation. Linear mixed-effects models are then employed to assess how gaze strategies relate to lateral control and longitudinal speed.

2. Methodology

2.1. Instruments

2.1.1. Driving simulator

The driving simulator used in this study was a fixed-base system (AVSimulation, France), shown in Fig. 1a, and located at the Road Safety Laboratory, Politecnico di Torino. The simulator mimicked a real vehicle cockpit, including a steering wheel with force feedback, a three-pedal system (clutch, brake, accelerator), a six-speed manual gearshift, and a side control panel with a start button, horn, and handbrake controls. A 9-in. display displayed the vehicle's instrument cluster.

Three 32-in. Full HD Samsung LCD monitors, arranged with the two side screens angled at approximately 25 degrees, provided a 130-degree field of view to simulate peripheral vision. Participants viewed the display from a distance of 0.7 to 1 m (depending on the position of the driver's seat). In combination with the graphics card, the monitors refreshed the displayed images at a rate exceeding 50 Hz. The simulation system was operated via three dedicated computers. The simulation environment was developed and managed using SCANeRStudio™. The simulation update rate was 100 Hz. The simulator was tested and shown to be reliable for modelling both longitudinal and lateral vehicle behaviour (Bassani et al., 2018; Catani & Bassani, 2019; Karimi et al., 2020; Mao et al., 2025).

2.1.2. Eye-tracker

Eye movements during the driving experiment were recorded using a head-mounted eye-tracking system, as shown in Fig. 1b (Pupil Core by Pupil Labs, Germany). This system is commonly used in driving simulation studies for its accuracy and non-intrusive design. It included a high-resolution front-facing world camera capable of recording at up to 1920 × 1080 pixels at 30 frames per second, with a 100-degree field of view and a latency of 5.7 ms. Additionally, it was equipped with two infrared eye cameras operating at 120 Hz, with a resolution of 640 × 480 pixels and the same latency.

Eye-tracking data were collected and processed using the Pupil Labs software suite (version 3.5.1), which includes tools for real-time data acquisition, offline analysis, and gaze mapping. During the experiment, Pupil Capture was used for real-time pupil detection and gaze tracking, while Pupil Player facilitated post-session video analysis and data extraction.

Fixation heatmaps (Fig. 3) were generated in Pupil Capture/Player using the Surface Tracker plugin. A planar surface corresponding to the simulator display was defined with fiducial markers on the screen. For each world-camera frame with sufficient detected markers, Surface Tracker computes the transformation from the scene-camera image to surface coordinates. It automatically maps gaze and fixation data to surface coordinates. Heatmaps were produced in the “Gaze within each surface” mode. This mode visualises the distribution of gaze points on each surface (simulator displays), aggregated over the curve-negotiation interval. The mapping uses surface tracking and does not require head-pose estimation. Because the driving scene is dynamic, heatmaps are shown as time-aggregated summaries. They are used only to illustrate overall gaze concentration during the curve interval, providing context to support strategy-coding decisions.

2.1.3. Eye-tracker calibration, validation, and data quality

Eye tracker setup and calibration were performed in Pupil Capture (Kassner et al., 2014) in accordance with the manufacturer's recommended procedure. Pupil detection quality was monitored using the confidence metric, and calibration proceeded only after stable pupil detection was achieved (in practice, confidence >0.8). Calibration used the Screen Marker calibration choreography on the simulator's central display, followed by a validation phase using the Accuracy Visualizer plugin, which reports accuracy as the mean angular offset between gaze and validation targets and precision as the root mean square angular distance between successive samples during fixation. If the RMS angular offset was greater than 1°, the observation was discarded.

Wearable eye tracking is subject to residual gaze-mapping uncertainty and potential calibration degradation over time due to head and facial movements, as well as headset slippage (Hooge et al., 2023). Consistent with this, additional validation was performed at the end of each drive to estimate any accumulated tracking error. Recordings were inspected offline in Pupil Player, with post hoc pupil detection and gaze calibration applied as needed, and the best-performing calibration was retained based on the Accuracy Visualizer output. In terms of magnitude, Pupil Labs reports typical calibrated accuracy in the sub-degree range for 2D gaze mapping and in the 1.5–2.5° range for 3D mapping. Additionally, independent evaluation (Hooge et al., 2023) of wearable eye trackers shows that accuracy can degrade with increasingly dynamic head and body movements, with errors typically below 3 degrees but occasionally larger in highly dynamic conditions.

Because participants were seated and the experiment was conducted in a fixed-base simulator, head and body movements were limited, which is expected to reduce the likelihood of significant headset slippage compared with highly dynamic tasks. Nevertheless, eye-data quality issues still occurred. Across the experiment, 512 driver–curve observations were collected (32 drivers × 16 curves). Of these, 449 were retained for analysis, and 63 driver–curve observations were discarded due to reduced pupil-detection quality. All curve observations for two drivers were removed, and a subset of observations for six additional drivers was discarded due to these eye-data quality issues.

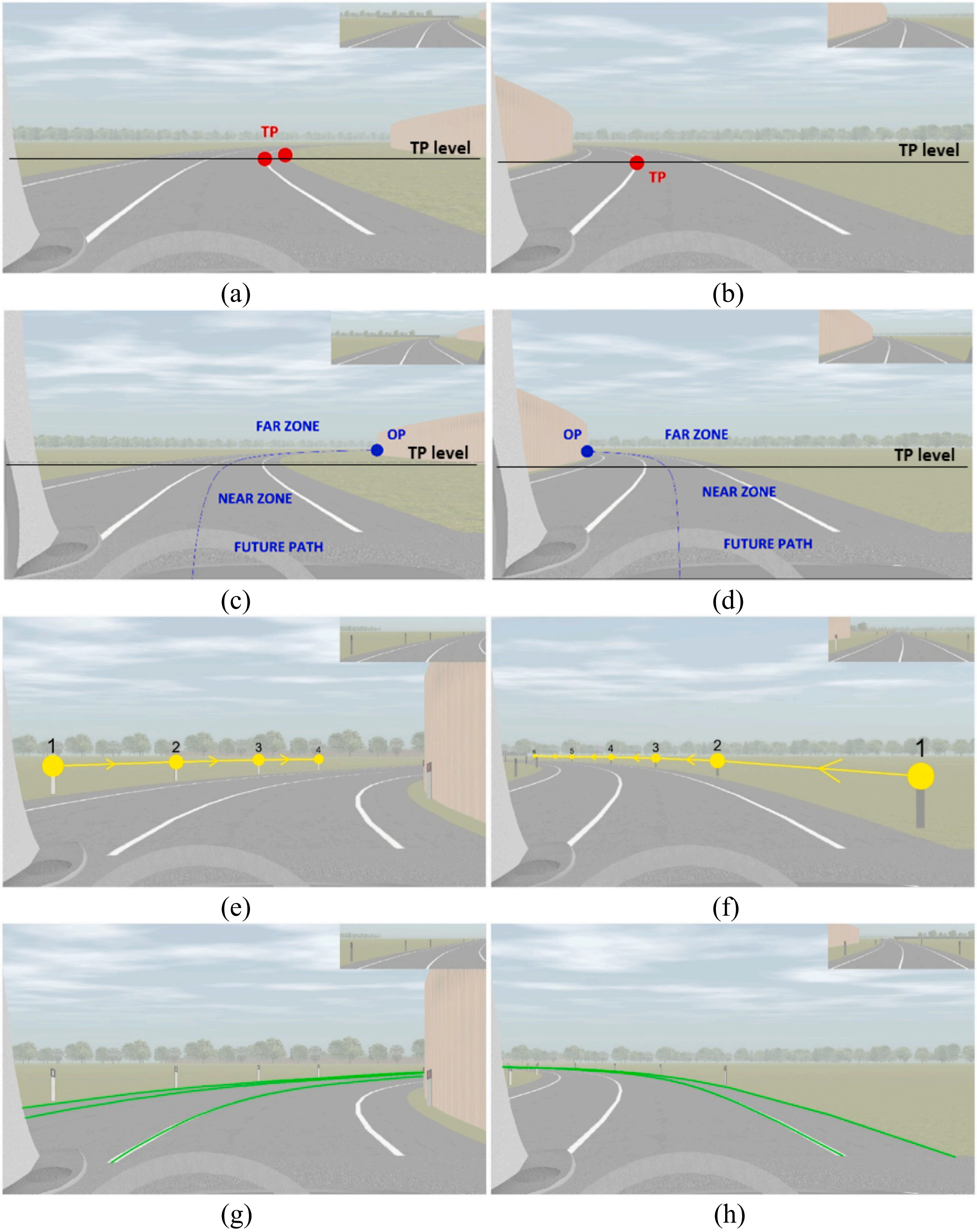


Fig. 2. Different gaze strategies for both left- and right-hand curves: (a) and (b) TP; (c) and (d) FP; (e) and (f) FXP; (g) and (h) EX.

2.2. Experimental design and test tracks

Using a two-level factorial design, this study comprised four blocks, with one centre point per block, to account for curvature in the response surface. The factors considered were: (i) *curve radius* (100 and 600 m); (ii) *sight obstruction*, defined as the lateral distance from the shoulder (0.6 and 15 m); (iii) *curve direction* (right and left); (iv) *presence of road markings* (yes, no); and (v) *presence of post-mounted delineators* (yes, no). Each block consisted of 16 combinations of these factor levels, including a curve radius of 350 m and a sight obstruction of 7.8 m, in combination with other categorical factor levels as centre points, representing 16 different curves. The block structure caused confounding of two three-way interactions and one four-way interaction. Four two-lane roads were designed, each with 16 curves separated by 400 m-long straights, with the order of the curves randomised. The 400 m-long straights ensured that the curves could be considered independent (Aminfar et al., 2023; Dhahir & Hassan, 2019). Tables A.1 to Table A.4 in Appendix A shows the experimental design and the four test tracks. The two-lane roads had a lane width of 3.75 m and a shoulder width of 1.50 m. Each participant drove on one road (i.e., one block); therefore, with eight replications of this experimental design, a total of 32 participants were included.

2.3. Participants

According to the World Medical Association (2025), 32 licensed Italian drivers voluntarily participated in the study without any compensation or rewards. However, the data from two drivers had to be excluded due to insufficient eye-tracking data quality. The remaining 30 participants included an equal number of men and women, aged between 20 and 59 years (M = 28.5 y; SD = 9.6 y). They had held their driving licences for between 1 and 33 years, with a mean duration of 9.5 years (SD = 8.3 y). On average, they reported driving approximately 13,436 km annually, although this varied widely (SD = 13,361 km); Fig. B.1 in Appendix B shows the distribution of annual driving kilometrage. Additionally, they had been involved in an average of just over 1.5 crashes (SD = 1.8).

2.4. Experimental protocol

For each participant, the experiment followed the same process, divided into five main phases: (i) a training session (approximately 10 min, including 5 min of driving) to familiarise drivers with the driving simulator, during which the simulator setup and controls were explained, and potential simulator sickness was discussed; (ii) setting up the eye-tracking device with Pupil Capture, including calibration and validation to ensure precise pupil detection; (iii) the simulated driving task, where each participant drove the assigned scenario under controlled environmental conditions; (iv) validating the experiment through post-drive checks in Pupil Capture to estimate possible tracking errors caused by head or facial movements; and (v) completing a post-drive questionnaire to gather feedback on the virtual driving experience and potential symptoms of simulator sickness.

2.5. Gaze strategies for curve negotiation

In this study, four distinct gaze strategies were identified and categorised as follows:

1) Tangent Point (TP) strategy: In the TP strategy, the driver focuses on the point where their gaze direction becomes tangent to the curve. This point can be identified either through road markings or along the road edges that separate the carriageway from the grassy shoulder. The TP is located inside the curve; therefore, in right-hand curves (Fig. 2a), the reference elements for drivers are the right longitudinal marking and the right edge of the road. In left-hand curves (Fig. 2b), the TP was identified at the central longitudinal marking when present (Chattington et al., 2007; Lappi et al., 2013).
2) Future Path (FP) strategy: The FP strategy was established by Lappi et al. (2013). Building on the work of Land and Horwood (1995) and Salvucci and Gray (2004) and following Lappi et al. (2013), the scene is divided into a near zone and a far zone at the TP level, defined as the level in the visual field corresponding to the TP (i.e., the same vertical visual elevation as the TP). The near zone refers to the roadway between the vehicle and the TP level, whereas the far zone corresponds to the visible roadway beyond the TP level up to the occlusion point (OP). OP is the farthest point on the future path that remains visible, as defined by Lehtonen et al. (2012). Observing this point enables drivers to detect potential oncoming vehicles and/or obstacles along the future path. Therefore, cases in which drivers adopted the future-path strategy were further classified based on the observed point's position (near zone, far zone, or OP). No specific roadway elements were designated for this strategy, as drivers mainly focused their gaze on the anticipated trajectory, which was approximately aligned with the lane centreline. Fig. 2c and Fig. 2d illustrate examples of the FP strategy for right-hand and left-hand curves, respectively.
3) The fixed point (FXP) strategy: FXP refers to repeated sampling of discrete, fixed landmarks in the road scene during curve negotiation. Wann and Land (2000) describe how, when gaze is held on a stable reference, the time-varying gaze direction relative to the vehicle's heading can provide information relevant to curvature estimation. In the present context, the repeatedly sampled fixed references were not points on the future path but roadside landmarks along the road edge, specifically post-mounted delineator posts. FXP was identified when drivers produced a characteristic sequence of brief fixations on successive delineators, separated by saccades, typically progressing from one post to the next as the vehicle advanced through the curve (see Fig. 2e and Fig. 2f).
4) External (EX) strategy: Ultimately, video and heatmap analysis identified a fourth gaze strategy, different from the previous ones and, to our knowledge, not explicitly described in earlier research. Han et al. (2019) only noted that, in some cases, drivers looked

at markings outside the curve during negotiation. Some drivers directed their gaze toward the outer part of the curve and, along the chosen element (road marking or edge), they moved their gaze while keeping a constant angle between the line of sight and the vehicle's direction. In this case, the road elements referenced by drivers were either the horizontal road markings, when present, or the road edges. In right-hand curves (Fig. 2g), drivers focused on the centreline marking as well as the left longitudinal marking and the left road edge. In left-hand curves (Fig. 2h), drivers instead concentrated on the right longitudinal marking or the right road edge.

2.6. Manual coding and decision rules

An instructed observer coded gaze strategy by reviewing the synchronised world-camera video with the time-resolved gaze overlay and fixation markers, supported by the fixation sequence during the curve-negotiation interval. Heatmaps were used only as time-aggregated illustrative summaries and as supportive context for the final coding decisions.

For each curve, the observer assigned a single prevailing strategy label using the following rules:

- FXP was assigned if gaze showed repeated brief fixations on delineator posts, with saccades between posts, forming a post-to-post sampling pattern as the vehicle progressed through the curve.
- EX was assigned if gaze was directed predominantly to outside-of-curve elements, maintained along the outside edge or markings, without the discrete post-to-post fixation hopping that characterises FXP.
- TP was assigned if fixations were predominantly maintained in the inside-edge/TP region of the curve, supported by the inside lane boundary and its marking or edge, without sustained sampling of the lane-centre future path and without post-to-post sampling.
- FP was assigned when fixations were predominantly directed to the roadway ahead along the intended travel lane, broadly aligned with the lane centreline. This included fixations in the near and far zones, separated at the TP level. Fixations below this TP level were classified as "near-zone FP", whereas fixations above the TP level toward the visible roadway ahead were classified as "far-zone FP" up to the "OP", which lie close to the inside edge of the near barrier (a wall in this study).

Residual gaze-mapping offsets are most relevant when candidate reference regions are close in the visual field, particularly around the TP level, where TP-region sampling can lie near far-zone or occlusion-point viewing. In such cases, fixations were interpreted with respect to the closest plausible support element/region visible in the synchronised world video (e.g., inside edge/TP region versus the travel-lane corridor ahead), while explicitly considering the potential for spatial proximity and overlap between candidate regions in curve-driving scenes as discussed by Lappi (2014). Decisions were based on the time-resolved fixation sequence over the full curve interval, not on single fixations or heatmap peaks. Potential borderline cases are most likely between FP subtypes (far zone versus occlusion point, OP), but these remain within the FP category and therefore do not change the primary four-category strategy variable used in the statistical models. As discussed in Section 2.1.3, observations with insufficient eye-tracking data quality were excluded to minimise the impact of calibration loss and tracking error.

The observer was also advised to report any prevailing strategy that did not fit these categories, although no additional categories were required. Another observer randomly checked 20% of the results to ensure the accuracy of the selected gaze strategies. Representative examples are provided in the Supplementary material (Video S1–S6).

Gaze strategy was operationalised at the curve level as a categorical label representing the prevailing gaze strategy over the curve-negotiation interval. Although drivers may shift gaze strategy within a curve, each curve was assigned a single strategy label for modelling purposes, based on the fixation sequence and the support elements observed in synchronised world video and fixation overlays. The prevailing strategy was defined as the gaze pattern that accounted for the largest share of the curve-negotiation interval, as judged by the relative prevalence of fixation sequences consistent with each strategy during the manoeuvre. When a secondary pattern was clearly present, it was recorded as a secondary gaze strategy. Across the 449 usable curve observations, a secondary mechanism was identified in 77 cases. The statistical analyses used the prevailing strategy label for each curve (choice occasion).

2.7. Panel-data mixed logit model of gaze strategy choice

The choice of gaze strategies was modelled within a random-utility framework that considers repeated observations from the same driver. The dependent variable equals the prevailing gaze-strategy label assigned to each curve (choice occasion). Let $i = 1, \ldots, N$ denote drivers, $t = 1, \ldots, T$ indicate curves (choice occasions) driven by driver i, and $a \in \{\text{TP, FP, EX, FXP}\}$ represent the four gaze strategies (i.e., the alternatives). The latent utility that driver i derives from gaze strategy a at curve t is represented by U_{iat}, as shown in Eq. 1:

$$U_{iat} = \mu_a + \eta_{ai} + \boldsymbol{x}_{it}\boldsymbol{\beta}_a + \varepsilon_{iat} \tag{1}$$

where $\mu_a + \eta_{ai}$ is called the alternative-specific constant (ASC); μ_a is the population-mean alternative-specific constant for alternative a, η_{ai} is a driver-specific deviation from that mean, $\boldsymbol{x}_{it}$ denotes the vector of case-specific (curve-level) and individual-specific covariates, $\boldsymbol{\beta}_a$ are alternative-specific slope coefficients, and ε_{iat} is *i.i.d.* type-I extreme-value distributed random error. The vector of random intercepts, $\boldsymbol{\eta}_i = (\eta_{FP,i}, \eta_{OP,i}, \eta_{FXP,i})^{\mathrm{T}} \sim N(\mathbf{0}, \boldsymbol{\Sigma})$, introduces unobserved, driver-level heterogeneity and induces serial correlation across curves within the same driver; a full (unrestricted) correlation matrix $\boldsymbol{\Sigma}$ was estimated. For identification, the TP gaze strategy serves as the base, so $\mu_{\mathrm{TP}} = 0$ and all slopes are interpreted relative to TP. Conditional on $\boldsymbol{\eta}_i$, the probability that driver i selects gaze strategy a on

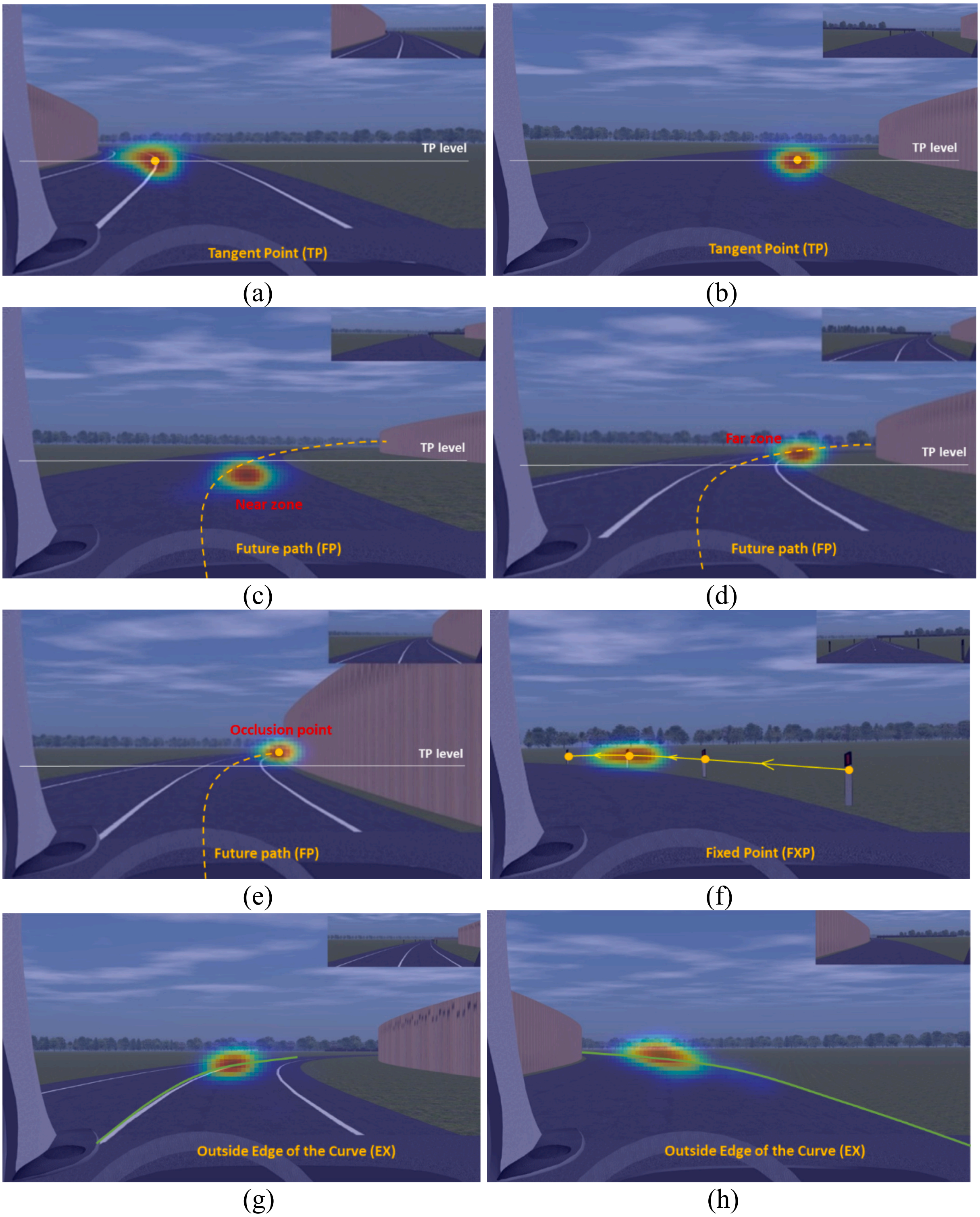


Fig. 3. Representative fixation heatmaps and identified gaze strategies. Note: Heatmaps are time-aggregated and shown for illustration only; strategy coding relied on the time-resolved fixation sequence in synchronised world video (see Supplementary material, Video S1–S6).

curve t follows the multinomial-logit form as presented in Eq. 2. Unconditional probabilities integrate over the mixing distribution using Eq. 3 and the panel log-likelihood equals as Eq. 4:

$$P_{iat}(\boldsymbol{\eta}_i) = \frac{\exp(U_{iat})}{\sum_{b\in\{TP,FP,EX,FXP\}}\exp(U_{ibt})} \tag{2}$$

$$P_{iat} = \int P_{iat}(\boldsymbol{\eta})\varnothing(\boldsymbol{\eta} \mid \mathbf{0}, \boldsymbol{\Sigma})\, d\boldsymbol{\eta} \tag{3}$$

$$\boldsymbol{LL}(\boldsymbol{\theta}) = \sum_{1=1}^{N}\int\left[\prod_{t=1}^{T_i}\prod_{a}P_{iat}(\boldsymbol{\eta})^{y_{iat}}\right]\varnothing(\boldsymbol{\eta} \mid \mathbf{0}, \boldsymbol{\Sigma})\, d\boldsymbol{\eta} \tag{4}$$

where, $\varnothing(\boldsymbol{\eta} \mid \mathbf{0}, \boldsymbol{\Sigma})$ denotes the probability density function of a multivariate normal (Gaussian) distribution with mean vector **0** and covariance matrix **Σ**. The binary indicator y_{iat} identifies the gaze strategy observed ($y_{iat} = 1$, if gaze strategy a was used on curve t by driver i, otherwise 0).

Parameters were obtained by **maximum simulated likelihood** with quasi-random low-discrepancy draws (Hammersley sequence; 1500 points), which provide stable approximations to the integral in Eq. 3 and Eq. 4. Driver-clustered (robust) standard errors were computed to protect inference against any residual within-driver dependence beyond the random effects. The panel-data mixed logit model was estimated using *STATA* statistical software (StataCorp, 2017) via the *cmxtmixlogit* command.

2.8. Modelling driving performance using linear mixed-effects models

To understand how the gaze strategy employed by the driver during curve negotiation affects driving performance — specifically, mean speed (MS) from the start to the end of the curve, mean lateral position (MLP) relative to the lane centreline over this segment, and the standard deviation of lateral position (SDLP) — linear mixed-effects models were utilised. The models incorporated both the observed gaze strategies and the experimental factors discussed in Section 2.2 as predictors to isolate the impact of gaze strategy on driving performance. Eq. 5 presents the general form of the linear mixed-effects model:

$$y_{ij} = W_{ij}\beta + u_i + \varepsilon_{ij} \tag{5}$$

where y_{ij} denotes the value of the response variable recorded for participant i at observation j. W_{ij} is the matrix of covariates included as fixed effects, and β is the vector of fixed-effect coefficients. The term u_i represents a participant-specific random intercept, accounting for systematic differences in baseline performance between participants. The residual term ε_{ij} captures remaining unexplained

Table 1
Estimated panel-data mixed logit model (Significance: † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Note: TP is the base alternative; coefficients are relative to TP.

Population-mean alternative-specific constants, μ_a			
Alternative	Coefficient	Robust SE	p
FP	2.1953	0.9489	0.021
FXP	−1.0062	1.9477	0.605
EX	−7.2758	2.8358	0.010
Random effects, η_{ai} (multivariate normal on alternative-specific constants)			
Parameter	Estimation	Robust SE	p
SD (FP)	1.8594	0.4889	–
SD (FXP)	4.2807	0.7571	–
SD (EX)	5.7457	1.1302	–
corr (FP, FXP)	0.8391	0.0875	< 0.001
corr (FP, EX)	0.6696	0.0962	< 0.001
corr (FXP, EX)	0.7793	0.0860	< 0.001
Fixed slopes by alternative *(β relative to TP; SE in parentheses)*			
Covariate	FP, β (Robust SE)	FXP, β (Robust SE)	EX, β (Robust SE)
curve radius	−0.0017 (0.0007) *	−0.0049 (0.0014) ***	−0.0009 (0.0012)
years_licensed	0.0931 (0.0526) †	0.1458 (0.0968)	0.2704 (0.0936) **
presence of post-mounted delineators (no)	−0.3602 (0.4294)	−30.2041 (0.7165) ***	2.0322 (0.8889) *
presence of road markings (no)	1.7904 (0.6364) **	3.7476 (0.7667) ***	2.8033 (0.8687) **
curve direction (right)	−0.9796 (0.5075) †	−2.8861 (1.1204) **	−5.8842 (1.8675) **
Model & sample summary			
Item		Value	
Log simulated (pseudo)-likelihood		−267.19381	
Wald χ^2 (df = 18), p		18,814.21, < 0.0001	
Panels (drivers)		30	
Cases (driver×curve)		449	
Alternatives per case		4	
Observations		1796	

variability at the observation level. Both u_i and ε_{ij} are assumed to follow a normal distribution. An overview of the theoretical background and estimation methods for linear mixed-effects models can be found in West et al. (2022).

3. Results

Fig. 3 displays fixation heatmaps during curve negotiation and shows that combining them with gaze-movement data reveals distinct gaze strategies. Figs. 3a and Fig. 3b illustrate TP gaze strategies that use the horizontal road markings and road edges as support elements.

Fig. 3c, Fig. 3d, and Fig. 3e show FP gaze strategies, including near zone, far zone, and occlusion point, respectively. Fig. 3f presents the FXP gaze strategy, which was supported by post-mounted delineators. Finally, Fig. 3g and h show the gaze strategy for elements outside the curve. Raw data showed that TP, FP, FXP, and EX strategies were chosen in 17.4%, 66.5%, 7.4%, and 9.0% of cases, respectively.

3.1. Models estimation and interpretation

As shown in Table 1, the panel-data mixed logit model was estimated using 449 driver–curve choice occasions contributed by 30 drivers (1796 observations; four alternatives per occasion). The joint Wald test of the fixed effects rejected the null hypothesis that all fixed-effect coefficients are zero (Wald $\chi^2 = 18{,}814.21$, $p < 0.0001$), indicating that the included predictors jointly contribute to the model.

The population-mean baseline utility for FP gaze strategy was significantly higher than TP at 95% confidence level ($\mu_{FP} = 2.1953$, $p = 0.021$; note that $\mu_{TP} = 0$), which means that, for a typical driver on a typical curve, by considering all road and driver factors the same, FP starts more attractive than TP gaze strategy. Hence, drivers are more likely to use FP than TP gaze strategies. However, FXP did not differ statistically from TP at the 95% confidence level ($p = 0.605$). The EX strategy exhibited a baseline negative to TP ($\mu_{EX} = -7.2758$, $p = 0.010$), which implies that drivers typically preferred the TP gaze strategy over the EX strategy.

The random alternative-specific constants (i.e., η_{ai}) show driver-level heterogeneity in baseline tendency to use each gaze strategy. The large standard deviations of three gaze strategies of FP, FXP, and EX exhibited substantial spread in inherent drivers' preferences, which were precisely estimated. The most remarkable heterogeneity in drivers' choices was observed for FXP and EX (SD (FXP) = 4.2807, SD (EX) = 5.7457) relative to the TP strategy. Additionally, the correlation between the driver-specific baseline preferences was all positive and statistically significant ($p < 0.001$). Drivers who prefer to use one non-TP gaze strategy (i.e., FP, FXP, and EX) also tend to use one another; in other words, those who favour TP tend to be less inclined toward all non-TP strategies.

As shown in Table 1, a larger curve radius considerably lowered the likelihood of selecting FP and FXP compared to TP strategies. An increase of 100 m in the curve radius decreased the likelihood of using the FP and FXP gaze strategies relative to TP by 15.6% and 38.7%, respectively. However, the curve radius did not have a statistically significant effect on EX compared to the TP gaze strategy at the 95% confidence level. Fig. 4a displays the average predicted probability relative to the curve radius for the gaze strategies across all observations. The aforementioned relative effect is clearly visible in the figure. Nonetheless, Fig. 4a indicates that increasing the curve radius results in only minor changes in the average predicted probabilities of employing EX and FP gaze strategies.

Table 1 shows that as the years licensed increase, the likelihood of using the EX gaze strategy relative to TP rises significantly; each

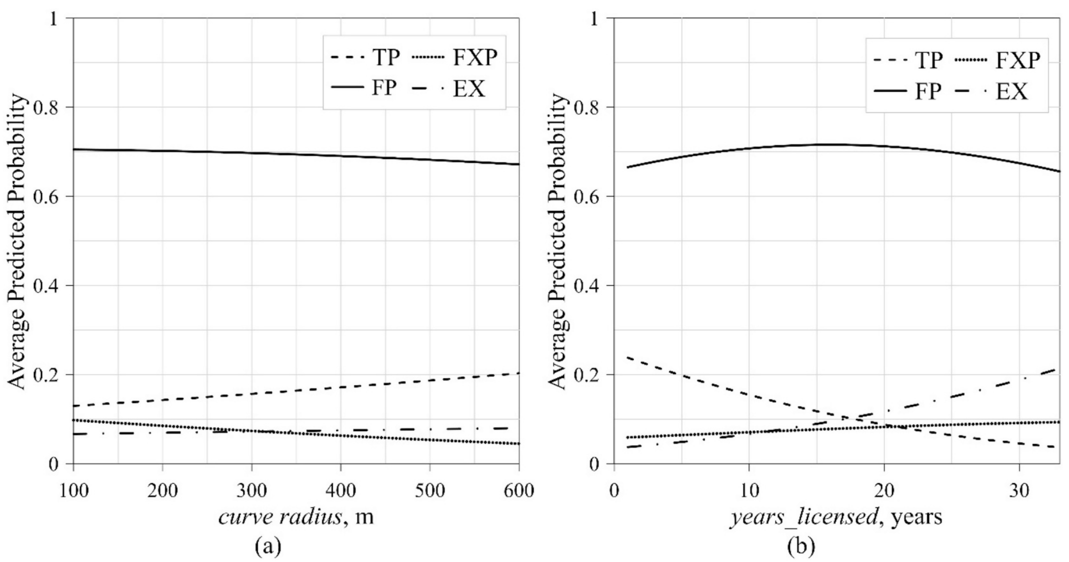


Fig. 4. Average predicted probability of choosing each gaze strategy as a function of (a) curve radius and (b) years licensed.

additional year is linked to about a 31% higher chance of choosing EX over TP. However, the likelihood of using FP and FXP compared to TP does not change notably with years licensed at the 95% confidence level. Fig. 4b similarly indicates that the average predicted probability of using FP and FXP remains largely unchanged with increasing years licensed. Additionally, Fig. 4b reveals that drivers with limited experience seldom use EX; as driving experience grows, the predicted probability of using EX surpasses 20%. In contrast, the estimated probability of selecting TP decreases from over 20% among novice drivers to less than 4% among highly experienced drivers.

Table 1 shows that the presence of post-mounted delineators significantly influences the odds of using FXP and EX gaze strategies compared to the TP. Fig. 5a illustrates that, as expected, without post-mounted delineators, the likelihood of using the FXP gaze strategy was zero. However, the presence of a delineator markedly increases the driver's average predicted probability of selecting the FXP strategy to approximately 13.6%. Conversely, the predicted probability of using EX decreases significantly from 11.2% to 3.6% when post-mounted delineators are present. For TP and FP, there was no significant difference in the probability of using these gaze strategies, although a slight decrease is observable.

Table 1 shows a strong association between road markings and gaze strategy choice. Compared to TP, sections without markings were associated with considerably higher odds of selecting FP, FXP, and EX. In line with this, Fig. 5b shows that when markings were present, the predicted average probability of TP increased sharply from 8.7% to 24%. Conversely, the probability of FXP significantly dropped from about 10% to 4%. For the two gaze strategies, FP and EX, a decrease in average probability was noted when road markings were present, although this was not significant at the 95% confidence level.

Table 1 shows that the right-hand curve corresponds to significantly lower odds of selecting FXP and EX than TP, whereas FP shows a marginal decrease relative to TP ($p = 0.054$). Fig. 6 indicates that the average predicted probability of TP increases significantly from about 12% (left) to 21% (right), whereas EX decreases significantly from about 12% to 2%. The direction of the curve did not significantly affect the probabilities of choosing the FP and FXP gaze strategies.

The variables of sight obstruction, participant gender and age, and average kilometres travelled per year did not significantly influence the likelihood of selecting gaze strategies. There was no interaction effect among these variables.

The linear mixed-effects models for MLP, the SDLP, and MS along the curves are presented in Appendix C. These models were based on 449 driver–curve observations. All three models showed a significant joint effect of the fixed predictors (Wald $\chi^2 > 115$, $p < 0.001$). Likelihood ratio tests showed that adding random effects significantly improved the models' fit at the 95% confidence level and accounted for heterogeneity between participants. The findings indicated that, in addition to road-related factors, the gaze strategy employed by drivers significantly influenced both the MLP and the SDLP. However, gaze strategies did not notably affect MS along the curve at the 95% confidence level.

Fig. 7a illustrates that the impact of gaze strategy on MLP varies with the curve's direction. For the right-hand curve, there were no significant differences in MLP among the gaze strategies at the 95% confidence level, and drivers tended to deviate from the lane centre toward the road edge. In the left-hand curve, the TP gaze strategy provided the best performance in maintaining the lane centreline. Conversely, the FXP and EX strategies performed the worst, yielding significantly larger MLP closer to the road centreline than the TP strategy at the 95% confidence level. However, Fig. 7b indicates that TP, FP, and EX showed no significant differences in terms of the SDLP. The poorest lateral vehicle control was observed with the FXP gaze strategy, which differed significantly from FP and EX at the 95% confidence level and from TP at the 90% confidence level.

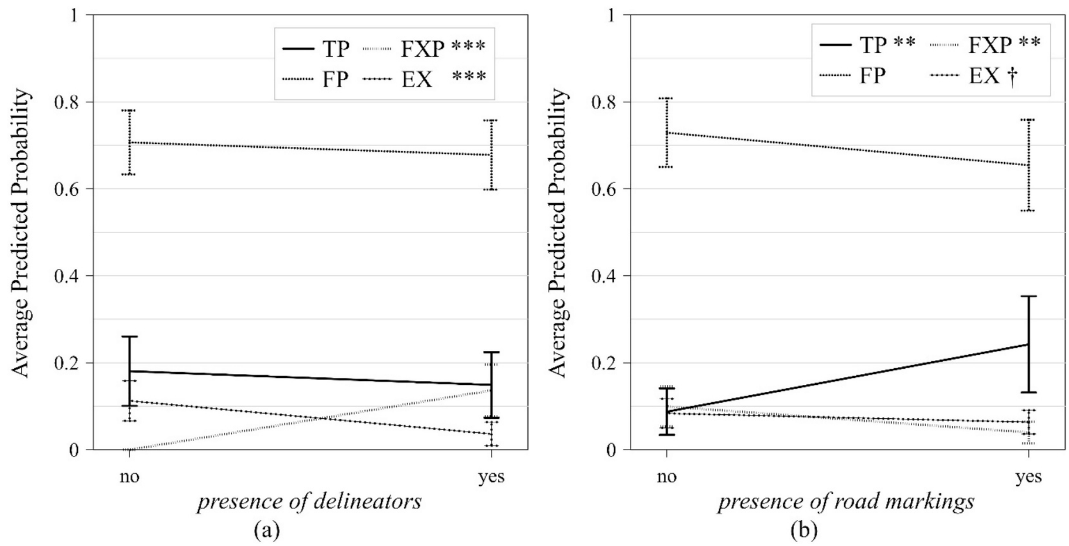


Fig. 5. Effect of (a) delineator and (b) road markings on average probability of choosing gaze strategies (Significance: † $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$).

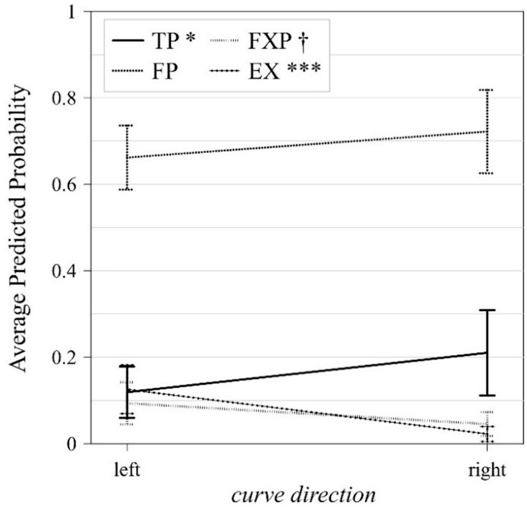


Fig. 6. Effect of curve direction on the average probability of choosing gaze strategies (Significance: † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

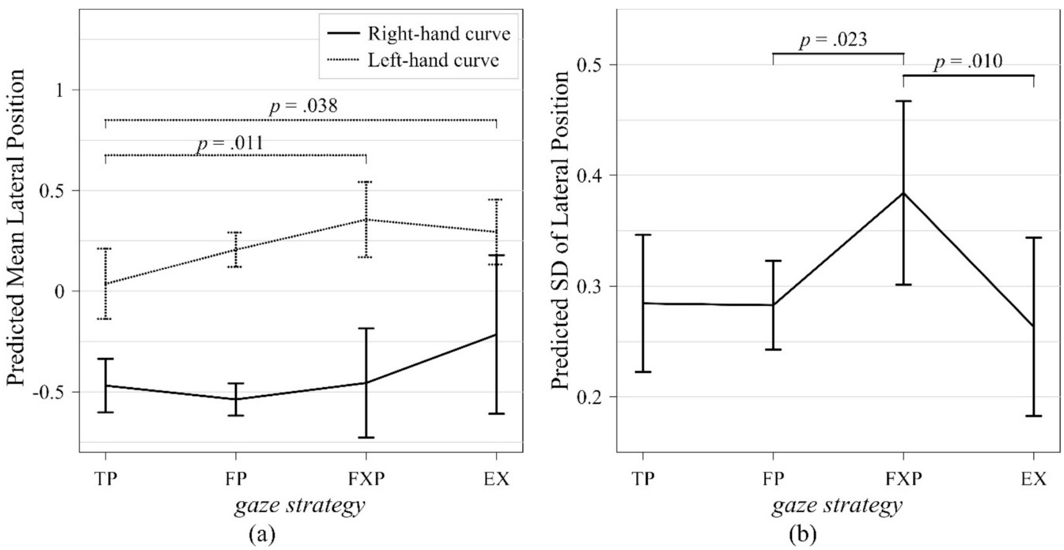


Fig. 7. Effect of different gaze strategies on (a) mean lateral position (MLP) and (b) SD of lateral position (SDLP).

4. Discussion

This study aimed to identify the factors that significantly influence the driver's gaze strategy choices when negotiating horizontal curves and, additionally, to examine how these strategies relate to lateral control performance. The findings indicated that both road design and driver-related factors significantly influence the likelihood of adopting different gaze strategies. It demonstrated that drivers do not adhere to a single gaze strategy but adjust their strategies depending on the situation. Furthermore, the results showed that, alongside road-related factors, the driver's gaze strategy during curve negotiation significantly impacts curve driving performance. The subsequent discussion interprets these findings and the related driving performance analysis in relation to previous research, considering their potential implications for driving safety and roadway design.

The predominant gaze strategy during curve negotiation, with an average estimated probability of 0.692 over all observations, was FP. The TP, EX, and FXP strategies had average estimated probabilities of 0.165, 0.073, and 0.070, respectively. However, the model output, after averaging out heterogeneity among drivers, showed that for the baseline case (i.e., a typical driver on a typical curve with all road and driver factors held constant), the probability of using FP was significantly higher than TP, while the probability of using EX was significantly lower than TP; no significant difference was found between TP and FXP. These results contrast with some classic findings but align with more recent studies. For example, Land and Lee (1994) reported that drivers' gaze was near the TP for roughly

75% of the time immediately after entering a curve; however, their sample consisted of only three drivers. Kandil et al. (2010) likewise found that drivers spent 59% of their time looking at the TP and lane marking just before entering the curve. In contrast, Robertshaw and Wilkie (2008) observed that drivers fixate on the TP between 7% and 20%, depending on lane width, and that they mostly fixate at the road centre and inner lane. Consistently, later studies reported FP as the predominant strategy (Itkonen et al., 2015; Lappi et al., 2013; Lehtonen et al., 2012). Notably, the results of mixed-effects models showed that FP and TP are also the strategies that support the most favourable lateral control, so that both are associated with relatively small MLP and low variability. In contrast, FXP, despite being chosen with a similar average probability as EX, leads to clearly poorer lateral control.

4.1. Effects of curve radius

The results of this study showed that increasing the curve radius increased the probability of using TP and decreased the probability of using FXP, whereas FP and EX showed no significant change. The observed effect of curve radius on gaze strategy diverges from several earlier findings. Kandil et al. (2010) reported the opposite trend, indicating that the TP strategy was more likely to be used for curves with a larger radius. It should be noted that the range of their studied curve was between 93.8 m and 1250 m, which is a wider range than the study range of 100–600 m. Robertshaw and Wilkie (2008), on the other hand, did not find any significant effect for curve radius, but they investigated curves in the narrow range of 60–120 m.

A geometric interpretation may explain the increase in TP use as the curve radius increases. As curvature tightens, the tangent point is perceived at a shorter preview distance and can lie very close in the visual field, which may limit its value for longer-horizon anticipation. In gentler curves, by contrast, the tangent point is typically easier to visually isolate and can serve as a stable reference point farther ahead, supporting earlier anticipatory steering. Accordingly, curve radius may shape strategy selection not only via overall curve demand but also by altering the salience and functional usefulness of the tangent point as a preview cue.

Since in this study the support element for the FXP strategy was post-mounted delineators, the results implied that on sharper curves, post-mounted delineators can help drivers negotiate the curve more effectively. This conclusion aligns with the previous finding that delineators are more effective at reducing crashes for curves with a radius less than 150 m (Srinivasan et al., 2009). However, the driving performance results highlight a potential downside of an FXP gaze pattern. When FXP was the prevailing strategy, drivers exhibited both larger mean deviations toward the centreline, especially in left-hand curves, and the highest SDLP. This finding should not be interpreted as evidence against delineators in general and suggests that, when other strong visual cues are available (clear edge lines, centreline, good visibility), a gaze strategy that jumps from one post to the next may provide a less continuous steering signal and therefore introduce noisier lateral control. Mecheri et al. (2024) outputs support this interpretation; they conclude that continuous lines have been shown to pull gaze back toward the lane centre and to reduce lane-departure frequency compared with broken or weaker delineation treatments. This study was conducted in clear, daytime conditions. However, post-mounted delineators are most useful at night and in harsh weather (Albin et al., 2016), when pavement markings and road edges may be partially or entirely obscured. In such situations, post-mounted delineators can become the primary reliable guidance cue, and an FXP-like strategy may still be beneficial compared with having no visual support at all.

4.2. Effects of curve direction

The direction of the curve also significantly influenced the gaze strategy a driver chose. Results indicated that drivers relied more on the TP strategy in right-hand curves than in left-hand curves, aligning with the findings of Kandil et al. (2010). Additionally, the EX gaze strategy was used markedly less in right-hand curves. The TP gaze strategy resulted in the smallest MLP on left-hand curves, without increasing variability compared to FP and EX. Since TP is positioned inside the curve, drivers focused their gaze on the centreline in left-hand curves, which marks the boundary of oncoming traffic. This provides a high-contrast, stable reference near the vehicle, allowing quick detection and correction of any drift toward the opposite lane, thereby preventing excessive encroachment. In right-hand curves, TP is located on the inner right edge. Fixating this boundary offers a reliable curvature cue (Land & Lee, 1994; Lappi et al., 2013), but safety considerations limit how close the vehicle can approach the shoulder. Consequently, drivers maintain a buffer at the edge, keeping the MLP under TP close to the lane centre and not significantly different from that of other strategies. Related experimental work shows that the lateral trajectory response can differ when gaze is explicitly directed. Mars (2008) reported contralateral trajectory deviations when drivers were required to fixate on targets near the TP, and Kountouriotis et al. (2015) similarly reported conditions in which drivers tended to steer away from eccentric fixation, which they interpreted as compensatory behaviour. In the present study, gaze was not prescribed, so the lateral buffer observed under TP is interpreted as a naturally adopted safety margin rather than a direct consequence of imposed fixation.

Although this safety buffer was generally smaller in right-hand curves, where it's measured relative to the centreline, the SD results show that TP does not compromise lateral stability. Variability under TP is comparable to that under FP and EX, indicating that steering corrections remain smooth when using this strategy. Mars and Navarro (2012) proposed a complementary interpretation of TP-area sampling: although gaze is focused near the TP, the peak of the distribution can be systematically shifted toward the lane centre, suggesting that drivers may use the TP as a salient dynamic reference while visually tracking a nearby ‘safety line’ marking an acceptable trajectory boundary, rather than fixating directly on the TP. This interpretation aligns with the current finding that, in right-hand curves, drivers maintain a conservative lateral distance from the shoulder even when using a TP strategy. Additionally, the present analysis treated TP as a strategy category and did not measure the precise angular deviation of gaze relative to the TP within that category.

The behaviour of FXP and EX relative to TP helps clarify these patterns. In left-hand curves, both FXP and EX direct gaze to the outside of the curve, away from the centreline. With EX, drivers follow a continuous outer edge or marking; with FXP, they fixate on individual delineator posts. This outward gaze makes it harder to monitor distance to the centreline, and both strategies show significantly larger MLP toward the centreline than TP. However, only FXP produces a clear increase in SDLP, consistent with the idea that EX still provides a continuous contour for steering. In contrast, FXP gives only intermittent samples at each post and leads to more irregular corrections. In right-hand curves, where the primary concern is running off the road rather than crossing the centreline, they tend to maintain a similar conservative lane position across strategies. That ceiling on outward deviation makes the MLP across strategies converge, although FXP still shows the highest variability and thus the least stable control.

4.3. Effects of delineators

As expected, in the absence of post-mounted delineators and other supporting elements, none of the drivers used the FXP gaze strategy. However, when post-mounted delineators were present, the probabilities of using the other gaze strategies decreased. In contrast, the probability of using FXP increased significantly, though only the reduction in the EX strategy was statistically significant. This suggests that drivers relied more on other sources of visual guidance, such as road markings and the road edge. Similar findings were reported by Han et al. (2019), who observed that wall-mounted delineators in tunnels could guide drivers' vision when navigating curves. They also found that, in some cases, drivers adopted an EX strategy by looking outside the curve during negotiation. In the absence of road markings, the probability of using the TP gaze strategy was significantly lower than when markings were present. This is likely because, without road markings, the only available support element was the road edge line, which was discernible in this study but may not always be, particularly at night. Mecheri et al. (2024) found that the type of edge-lane road marking significantly influenced drivers' gaze strategy, although they did not examine the presence versus absence of markings. A review by Babić et al. (2020) also concluded that road markings significantly affect road safety and driver behaviour, including lateral position and speed. As the performance analysis showed, however, a prevailing FXP strategy came at the cost of higher lateral variability, which indicates that, for daytime curves of the type studied here, delineator configurations that encouraged continuous following of the outer edge (EX) were preferable to those that promoted discrete post-to-post fixations (FXP).

4.4. Effects of sight obstruction

The results revealed that the sight obstruction factor was not statistically significantly associated with gaze-strategy selection. In this study, sight obstruction was operationalised as the lateral offset of roadside objects from the shoulder (0.6 vs 15 m). The range covered by this manipulation is limited, as both conditions still constrained the far preview to an occlusion point, and within this range, a systematic shift between the gaze-strategy classes was not observed. Future work should examine a wider spectrum of occlusion conditions, including situations with a clearly visible curve end, to better isolate how available preview influences strategy choice.

4.5. Effects of driver-related factors

The estimated model showed significant heterogeneity among drivers, implying that each driver's gaze strategy preferences can differ from those of others and that driver-related factors can substantially affect these preferences. The greatest heterogeneity in choices was observed for EX relative to the TP strategy, consistent with the effect of driving experience (years licensed). The results indicate that as experience increased, drivers tended to prefer EX over TP, while their preference for FP and FXP remained almost constant. In addition, the estimated correlations between the random parameters showed positive correlations among FP, FXP, and EX, indicating that drivers who favour one non-TP strategy are also prone to adopt the other non-TP strategies. In contrast, drivers with a strong preference for TP tend to use non-TP strategies comparatively little. The observed tendency for more experienced drivers to rely relatively more on EX is consistent with previous evidence that experience and expertise are associated with broader, more efficient visual search patterns, whereas novice drivers typically show truncated scan paths and reduced use of peripheral and contextual information (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Deery, 1999; Pammer & Blink, 2013, 2018). In this sense, a more substantial reliance on TP may reflect a more limited or conservative information-gathering strategy. At the same time, the increased use of EX by more experienced drivers aligns with the development of richer perceptual templates and more flexible visual sampling of the driving scene. At the same time, the performance results showed that EX maintained lateral variability at a level comparable to TP and FP, suggesting that this shift toward EX with increasing experience represents an adaptive broadening of gaze behaviour rather than a degradation of control.

4.6. Limitations

This study has some limitations. The experiments were conducted in a fixed-base simulator under daytime, clear-weather conditions, and the sample was limited to licensed Italian drivers. Real-world driving, night-time and adverse-weather conditions, and different traffic environments may produce different distributions of gaze strategies and different performance profiles, particularly for FXP when delineators become the primary source of visual guidance. Future research should therefore extend this work to on-road studies, a broader range of curve geometries, and automated classification of gaze strategies. Additional factors such as cognitive load, hazard presence, and driver state could also be examined to better understand how gaze control strategies are selected and how they interact with safety-critical events.

Curve radius was examined only within the range tested in this study (100–600 m). Very tight curves (e.g., ~50–60 m), where the tangent point may appear too close to support far preview, were excluded. Future work should extend the radius range to sharper bends to test whether TP use diminishes under those conditions and whether drivers shift to alternative gaze strategies.

5. Conclusion

This study investigated how road design elements and driver characteristics influence drivers' choice of gaze strategy during horizontal curve negotiation on two-lane rural roads, and how the prevailing gaze strategy relates to lateral control performance.

The results showed that drivers do not rely on a single gaze strategy. Strategy choice varied systematically with curve geometry and roadside guidance. FP was the most prevalent strategy overall, while the probabilities of TP, FXP, and EX varied with factors such as curve radius, curve direction, road markings, delineator presence, and driving experience. In terms of vehicle control, gaze strategy was associated with differences in mean lateral position and lateral variability, whereas mean speed showed no significant dependence on strategy.

These findings suggest that gaze strategy is a meaningful behavioural link between roadway design and lateral control in curves. In particular, roadway delineation and markings influence where drivers allocate visual attention and how they regulate lane position, with implications for curve design and countermeasure selection on rural roads. The results also highlight substantial between-driver differences in baseline strategy preferences, supporting the need to account for heterogeneity when modelling driver behaviour.

These results have several practical implications. The modelling framework can inform the design and evaluation of geometric elements, markings, and post-mounted delineators by quantifying how these treatments shift gaze behaviour. For example, post-mounted delineators appear particularly valuable on sharper curves to support FXP-based guidance, whereas continuous markings strengthen TP- and EX-based controls. The combined use of mixed logit and linear mixed-effects models also provides a basis for incorporating realistic gaze strategies and their performance consequences into advanced driver-assistance systems.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2026.103771.

CRediT authorship contribution statement

A. Karimi: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **E. Ardusso:** Writing – review & editing, Software, Methodology, Investigation, Formal analysis. **A. Portera:** Writing – review & editing, Software, Methodology. **M. Bassani:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

Appendix A

Table A.1
Experimental design for block 1.

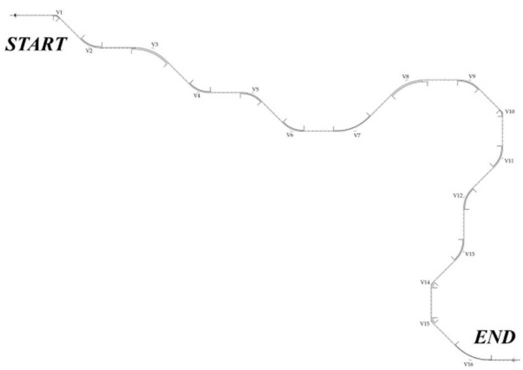
block	run	*curve radius*	*sight obstruction*	*curve direction*	*presence of road markings*	*presence of delineators*	test tracks
	1	100	0.6	right	yes	yes	
	2	350	7.8	left	no	yes	
	3	600	15	right	no	yes	
	4	350	7.8	left	yes	yes	
	5	350	7.8	right	yes	yes	
	6	350	7.8	left	no	no	
	7	600	0.6	left	yes	no	
	8	600	15	right	yes	no	
1	9	350	7.8	right	yes	no	
	10	100	0.6	right	no	no	
	11	350	7.8	right	no	no	
	12	350	7.8	left	yes	no	
	13	350	7.8	right	no	yes	
	14	100	15	left	yes	yes	
	15	100	15	left	no	no	
	16	600	0.6	left	no	yes	

Table A.2
Experimental design for block 2.

block	run	*curve radius*	*sight obstruction*	*curve direction*	*presence of road markings*	*presence of delineators*	test tracks

(*continued on next page*)

Table A.2 (*continued*)

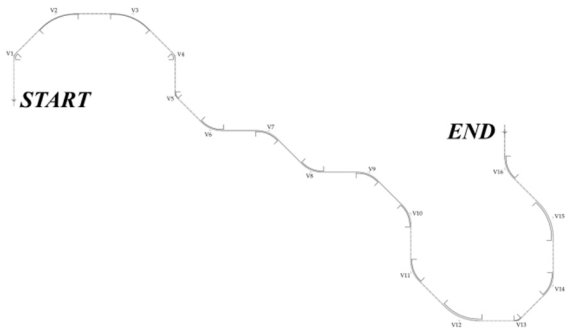
block	run	*curve radius*	*sight obstruction*	*curve direction*	*presence of road markings*	*presence of delineators*	test tracks
2	17	100	15	right	no	no	
	18	600	0.6	right	no	yes	
	19	600	0.6	right	yes	no	
	20	100	15	right	yes	yes	
	21	100	0.6	left	yes	yes	
	22	350	7.8	left	yes	yes	
	23	350	7.8	right	no	yes	
	24	350	7.8	left	no	yes	
	25	350	7.8	right	no	no	
	26	350	7.8	right	yes	no	
	27	350	7.8	left	no	no	
	28	600	15	left	yes	no	
	29	100	0.6	left	no	no	
	30	350	7.8	left	yes	no	
	31	600	15	left	no	yes	
	32	350	7.8	right	yes	yes	

Table A.3
Experimental design for block 3.

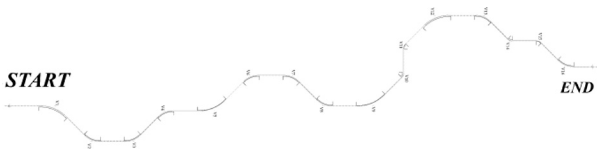
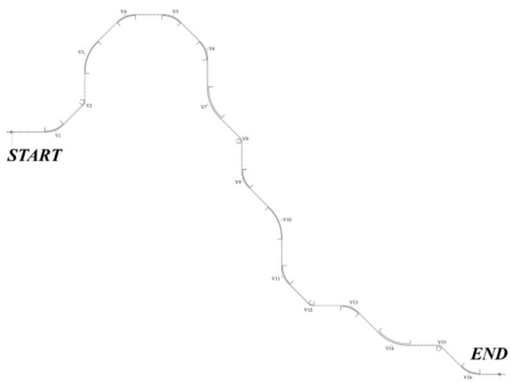
block	run	*curve radius*	*sight obstruction*	*curve direction*	*presence of road markings*	*presence of delineators*	test tracks
3	33	600	15	right	yes	yes	
	34	350	7.8	left	no	yes	
	35	350	7.8	left	yes	no	
	36	350	7.8	right	yes	yes	
	37	600	0.6	left	no	no	
	38	350	7.8	right	no	no	
	39	350	7.8	right	yes	no	
	40	350	7.8	left	no	no	
	41	600	0.6	left	yes	yes	
	42	100	15	left	yes	no	
	43	100	0.6	right	yes	no	
	44	600	15	right	no	no	
	45	350	7.8	right	no	yes	
	46	100	15	left	no	yes	
	47	100	0.6	right	no	yes	
	48	350	7.8	left	yes	yes	

Table A.4
Experimental design for block 4.

block	run	*curve radius*	*sight obstruction*	*curve direction*	*presence of road markings*	*presence of delineators*	test tracks
4	49	350	7.8	left	yes	yes	
	50	100	0.6	left	yes	no	
	51	600	0.6	right	no	no	
	52	350	7.8	right	no	no	
	53	350	7.8	right	yes	yes	
	54	350	7.8	right	no	yes	
	55	600	15	left	no	no	
	56	100	15	right	no	yes	
	57	350	7.8	left	yes	no	
	58	600	0.6	right	yes	yes	
	59	350	7.8	left	no	no	
	60	100	0.6	left	no	yes	
	61	350	7.8	right	yes	no	
	62	600	15	left	yes	yes	
	63	100	15	right	yes	no	
	64	350	7.8	left	no	yes	

Appendix B

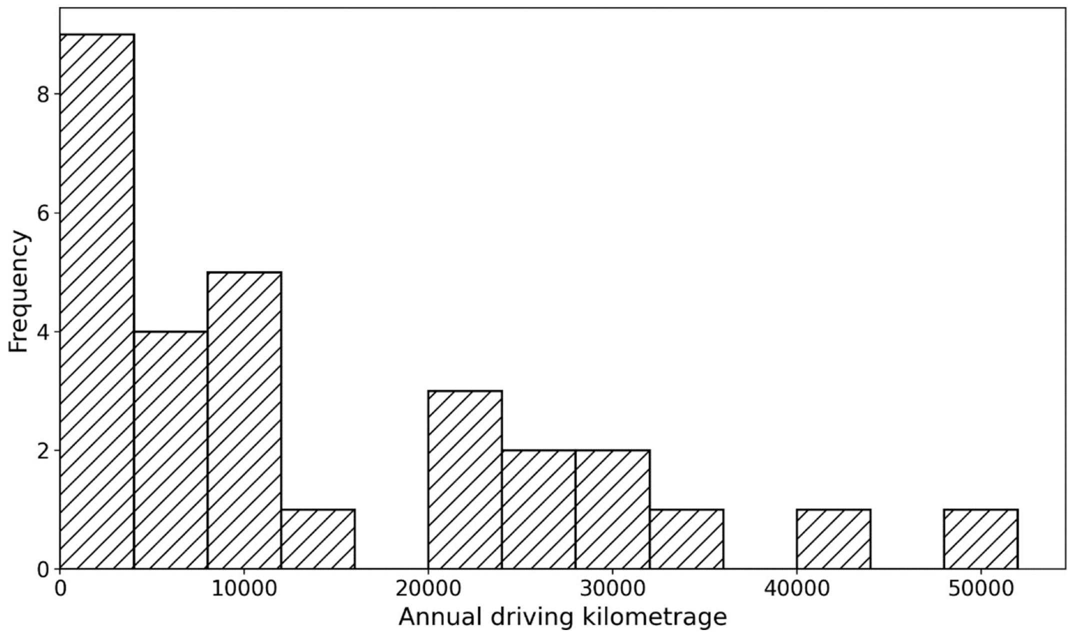


Fig. B.1. Distribution of annual driving kilometrage among experiment participants.

Appendix C

Table C.1
Estimated Mixed-effects model for mean lateral position from the lane centreline.

	β	Std. err.	p-value
gaze strategy			
FP	0.16950	0.07327	0.021
FXP	0.31907	0.10278	0.002
EX	0.25766	0.09450	0.006
curve radius	−0.00091	0.00013	< 0.0001
curve direction (right)	−0.96545	0.10380	< 0.0001
curve radius × *curve direction* (right)	0.00132	0.00018	< 0.0001
presence of road markings (no)	−0.23265	0.03270	< 0.0001
gaze strategy × *curve direction*			
FP. right	−0.23819	0.09000	0.008
FXP. right	−0.30576	0.15092	0.043
EX. right	−0.00391	0.18564	0.983
constant	0.46867	0.08124	< 0.0001
Random-effects parameters			
σ^2 of intercepts	0.00975	0.00455	–
σ^2 of residuals	0.10764	0.00745	–
# observations	449	–	–

Table C.2
Estimated Mixed-effects model for standard deviation of lateral position.

	β	Std. err.	p-value
gaze strategy			
FP	−0.00157	0.02368	0.947
FXP	0.09985	0.03911	0.011
EX	−0.02107	0.03789	0.578
curve radius	−0.00026	0.00004	< 0.0001
presence of road markings (no)	0.11669	0.01581	< 0.0001
constant	0.31562	0.02943	< 0.0001
Random-effects parameters			
σ^2 of intercepts	0.00492	0.00178	–
σ^2 of residuals	0.02587	0.00179	–
# observations	449	–	–

Table C.3
Estimated mixed-effects model for mean speed.

	β	Std. err.	p-value
gaze strategy			
FP	−1.69431	1.14111	0.138
FXP	−0.39643	1.91899	0.836
EX	0.06312	1.98691	0.975
curve radius	0.04352	0.00289	< 0.0001
curve radius × *curve direction* (right)	−0.01318	0.00402	0.0001
curve direction (right)	5.40489	1.58749	0.0001
constant	67.45823	2.77350	< 0.0001
Random-effects parameters			
σ^2 of intercepts	157.4975	41.84871	–
σ^2 of residuals	56.83699	3.92785	–
# observations	449	–	–

Data availability

Data will be made available on request.

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