Supplementary Methods & Results

Supplementary figure S1

Schematic illustration of the sequencing of a corner, and visual scene reference points used in this study projected onto an allocentric “map”. Figure is not to scale. Note that whereas the reference points determining phase sequencing have fixed allocentric locations, the visual reference points and future path in the driver’s field of view project into different points in the environment, as the car moves along the road.
The line from the tangent point to the centerline reference point defines the beginning of the far zone of the driver’s own lane, extending to the occlusion point or the exit point. In contrast to the points defining the curve-driving sequence (entry point, max. yaw-dot point and exit point) which, given a trajectory, have fixed locations on the road, the location of the near zone-far zone transition point moves along with the tangent point. TP and the future path FPRP1, FPRP2 and OP are thus all travel points, in that their allocentric location changes with the movement of the vehicle. In contrast, the turn point, maximum rotation point and exit point are fixed waypoints which have definite locations on the trajectory that do not change over time.
Supplementary Methods

Calibration & gaze quality

A nine-point calibration was performed by asking the subject to look at designated objects in the scene outside the garage. Successful calibration was verified by asking the subject to fixate the same objects again. If the online visualization of gaze position for some calibration points was off (by about two degrees or more), a recalibration was performed. On the road, maintaining calibration was verified by visual judgment between each run, by designating objects for the subject to look at. A gaze quality criterion of <0.2 supplied by the tracker software was used to exclude data before analyses.

Supplementary figure S2

Nine point calibration used to calibrate the eye-tracker. White dots are placed at the designated calibration points. The colored dots represent data-points of gaze position. The red rectangle indicates the part of the visual field where roadview falls in the experiment.
Horizontal and vertical gaze deviation (difference of median observed gaze position from designated target point) is under 2°. Open red circles: calibration datapoints from the current dataset. Closed black circles: calibration datapoints from a simultaneously collected dataset.
Supplementary method for Supplementary movies SM1 and SM2

s1_north_wire_video_scatter.mov
s1_south_wire_video_scatter.mov

(See Figure 4 in Methods). Video from one participant (subject 1, run1, northbound and southbound) shows the Bézier spline wireframe fitted onto the reference points in the image, giving us a representation of the road structure and allowing us to estimate the future path (thin dotted line). Small red dot indicates TP, green dot FP1 and black dot OP. The location along the route (m from beginning) is shown in the top right corner. The horizontal and vertical scales are gaze position angular coordinates in the vehicle frame of reference (zero is straight ahead).

The video was compiled as follows. Gaze data from all runs of this participant was matched to the time stamp of the video frame, and superimposed on the image based on the mapping from gaze angle to pixels. Results were calculated relative to reference points identified in each individual trial. Wireframe is based on the first run (from which the video image is). The participant’s four runs are represented by colors, the order is B-G-R-Y.

The turn points of the curves analysed in the results are at the following route locations:

North: 45 m, 697 m, 850 m, 935 m, 1351 m, 2153 m, 2440 m, 2556 m, 2823 m, 3081 m, 3241 m, 4332 m, 4795 m, 4883 m

South: 251 m, 579 m, 2203 m, 2468 m, 2590 m, 2934 m, 3099 m, 3972 m, 4299 m
**Supplementary method for Movie 1**

heat_all_release.mov

(See Figure 8 in Results). The heatmap video was compiled as follows. The reference point values from one run acting as prototype were resampled to 20Hz, determining the frames of the movie, and their respective location values. The corresponding route location values were retrieved, and the reference point angles and gaze data assigned to that location in the distance-based coordinate system were associated with each frame. The median value for each reference point vertical and horizontal coordinate was computed and the spline wireframe road-representation fitted to them, in the same way as was done for individual runs when computing future path reference points. Finally, the raw gaze data associated with the location was smoothed with a Gaussian kernel giving a pixelwise density estimate of gaze (in vehicle frame of reference) and this was drawn into the frame.

The reason for choosing a movie as presentation format, rather than producing a batch of static heatmaps of gaze (and reference points) is the fundamental problem of not having a "normalized" 2D or 3D space, into which the data could be usefully projected. The problem arises from the dynamic nature of the stimulus: the reference points constantly move relative to one another.

Consider gaze and reference points referenced to some coordinate system - vehicle, TP at the origin, FPRP1 at the origin, FPRP2 at the origin, the midpoint between FPRP1 and OP at the origin etc... Take for example the vehicle frame of reference, where the origin is at the locomotor heading (which is the one used in the movie). The location of any reference point is not time invariant. Now, take the tangent point frame of reference. Again, the location of all other reference points changes over time. An average heat map in any one coordinate system would effectively amount to superimposing all bends' observations into one picture, and as only one reference point can be placed at the origin, and the others will be blurred. Imagine projecting, for example, all entry phase OP positions into the y axis. They will not project to a point, but create a distribution. Now, if we take another bend, this distribution will be at a different place. Repeat this for TP (and other reference points) and all we are left with is a blur of overlapping distributions, with the distribution of gaze "somewhere in there". The movie was chosen over a static representation precisely because the pattern changes in time, and thus t is important to have the time coordinate represented, rather than collapsing all time points into one.
In TP centered coordinates (for example the contour map of Land & Lee, 1994), the future path becomes a blur. In an FP referenced map the TP becomes a blur, and it is not clear what fixed point on the FP should be chosen (no model gives one a priori, and determining it empirically is riddled with the problem of "contamination" by the presence of the tangent point nearby).

It is thus not obvious what coordinate system to use to make a readable heat map - when the reference points all move relative to the vehicle and relative to each other at different rates, as a function of time, and by a magnitude that is large in relation to the average distances between them.

Each frame of Movie 1 is a heatmap of gaze distribution data sampled at a specific route location, and the fact that the distribution in the movie is dynamic (changing in time) illustrates the limitations of static heatmaps (or distribution density estimates) in representing the data. It also illustrates the phenomenon of gaze "following" the pattern of elongation and subtraction of the future path in the far zone.

For visualization, an “across subjects” wireframe is computed from median position of the reference points at that route location in all trials, and a density distribution of gaze observations (all subjects, all four runs) associated with that route location are displayed. (Note that in computing the results the individual runs’ video frame image coordinates and eyetracker angular coordinates were associated based on their time stamp, which is more accurate because no “averaging” of the reference points’ angular positions occurs).
Supplementary Results

SUPPLEMENTARY TABLE T1

Averages of per-curve median distance between reference points in the entry phase, by curve direction.

<table>
<thead>
<tr>
<th></th>
<th>tp-fprp1</th>
<th>cl-fprp1</th>
<th>tp-fprp2</th>
<th>cl-fprp2</th>
<th>fprp1-fprp2</th>
<th>op-fprp1</th>
<th>op-fprp2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>15.6°</td>
<td>5.2°</td>
<td>10.7°</td>
<td>1.6°</td>
<td>5.5°</td>
<td>20.8°</td>
<td>15.7°</td>
</tr>
<tr>
<td>Right</td>
<td>4.8°</td>
<td>4.8°</td>
<td>3.1°</td>
<td>10.3°</td>
<td>5.8°</td>
<td>10.7°</td>
<td>5.5°</td>
</tr>
</tbody>
</table>

* the values in this column are equal to the value of the curve height parameter \( h \), because FPRP1 always lies horizontal to both TP and CL.
Individual subjects’ gaze data (top, left hand turns, bottom, right hand turns): Gaussian density estimate of vertical gaze position in 6° radius TP AOI as a function of $h$, indicating that the 6° AOI size is sufficient to capture the vertical variation in road-directed gaze. (The top and bottom edges only clip the very tails of the distributions).
The Approach phase

The Land and Lee (1994) results showed that the tangent point was likely to be fixated immediately before turn-in. Also, Kandil et al. (2010) limit their investigation to the early part of motorway ramps, because that is where they expected to see more tangent point orientation. Here, we present AOI gaze catch data for approach phases (up to 30 m prior to turn-in) from a subset of curves where the approach phase was clearly definable.

In the Results we concentrated, in contrast, on the entry phase (from turn point to the point of maximum rotation). There were three main reasons for this:

1. We were concerned with comparing the tangent point to future path reference points. In the approach phase all reference points even closer together (in the limit, seen from an infinite distance they would converge to a single point), thus making it even more difficult to assess the reference points separately. When the can is entering the bend, optic flow expands the roadview in the driver’s visual field, with the tangent point and occlusion point moving horizontally in the direction of the curve, and the vertical separation of the tangent point and future path increasing. This can be seen in Movie 1, as well as Supplementary Table T1, below.

2. Many of the bends on the road were S-bends. In this case there is no well-defined approach phase, the exit point of one curve becoming the turn point of the next, and the “approach” to the next bend is actually the exit of the previous bend. In this case there are two tangent points visible simultaneously, making it ambiguous where to place the TP and FPRP2 AOIs. (The FPRP2 the point where the spline representing future path intersects a vertical line running through the tangent point, there would be not only multiple tangent points, but also, potentially, multiple points where future path is in the same horizontal direction as the tangent point, as the road turns back on itself).

3. As a practical limitation, our Bézier curve model cannot at its present state of development “track” the road geometry reliably in connected bends where the curve immediately leads to the next.

Land and Lee studied a route consisting of many S-bends, and state that the first TP oriented
fixation occurred approximately 1-2 seconds before the car “entered the bend” (which they defined as zero crossing of the steering angle), and their data show that the frequency of tangent point oriented (3 degree radius AOI) fixations to be highest during the earliest part of the curve. In the first two seconds after turn-in gaze direction was within a 3 degrees of the tangent for about half of the time - but we also see that as the cornering sequence progressed the relative frequency of fixations in the direction of the tangent point direction progressively decreased. Had we studied gaze behavior in S bends we might have seen more TP orientation. How this would relate to AOI overlap and orientation to future path points remains to be seen.

SUPPLEMENTARY TABLE T2

Gaze catch and ambiguity for 3 degree AOIs in the Approach phase.

<table>
<thead>
<tr>
<th></th>
<th>Left catch</th>
<th>ambiguity</th>
<th></th>
<th>Right catch</th>
<th>ambiguity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>11.7%</td>
<td>67%</td>
<td>TP</td>
<td>44.7%</td>
<td>99%</td>
</tr>
<tr>
<td>CL</td>
<td>38.7%</td>
<td>99%</td>
<td>CL</td>
<td>40%</td>
<td>86%</td>
</tr>
<tr>
<td>FPRP1</td>
<td>28.9%</td>
<td>87%</td>
<td>FPRP1</td>
<td>49.2%</td>
<td>99%</td>
</tr>
<tr>
<td>FPRP2</td>
<td>37.8%</td>
<td>94%</td>
<td>FPRP2</td>
<td>41.7%</td>
<td>99%</td>
</tr>
<tr>
<td>OP</td>
<td>15.9%</td>
<td>59%</td>
<td>OP</td>
<td>28.8%</td>
<td>93%</td>
</tr>
</tbody>
</table>

SUPPLEMENTARY TABLE T3

Averages of per-curve median distance between reference points in the approach phase for left hand curves and right hand curves. Lower values than those observed for the entry phase (Supplementary Table T1) are due to the projection of the road in the visual field “opening up” due to visual flow during curve entry. Note that the approach values are computed only from a proper subset of the bends having an identifiable approach phase (not present in connected S-bends).

<table>
<thead>
<tr>
<th></th>
<th>tp-fprp1</th>
<th>cl-fprp1</th>
<th>tp-fprp2</th>
<th>cl-fprp2</th>
<th>fprp1-fprp2</th>
<th>op-fprp1</th>
<th>op-fprp2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>8.2°</td>
<td>2.8°</td>
<td>5.7°</td>
<td>0.9°</td>
<td>3.0°</td>
<td>11.9°</td>
<td>9.3°</td>
</tr>
<tr>
<td>Right</td>
<td>2.8°</td>
<td>2.8°</td>
<td>1.4°</td>
<td>5.8°</td>
<td>3.2°</td>
<td>6.6°</td>
<td>3.8°</td>
</tr>
</tbody>
</table>