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An eye-tracking, think-aloud on-road study**

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Which visual cues do drivers use to anticipate and slow down in freeway curve approach? An eye-tracking, think-aloud on-road study

Johan Vos^{a,*}, Joost de Winter^{b,2}, Haneen Farah^{a,3}, Marjan Hagenzieker^{a,4}^a Department of Transport and Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands^b Department of Cognitive Robotics, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands

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ABSTRACT

Although much research is done on speed and gaze behaviour inside curves, there is little understanding of which cues drivers use to anticipate and slow down while approaching curves. Therefore, an on road experiment was conducted in which 31 participants drove through six freeway curves in their own car. During the experiment, look-ahead fixations and speed were recorded using an eye-tracker and a GPS tracker, respectively. In addition to these measurements, the participants verbalised their reasons for changing speed. The distribution of fixations over various areas of interest was investigated around the start of deceleration before each curve and around the start of each curve. Verbalisation data were analysed to infer the number and types of reasons for changing speed and when these were mentioned together with mentions of deceleration before a curve. The results showed that before starting to decelerate, the participants fixated mostly on the Focus of Expansion and edges parallel to the curve trajectory, whereas most fixations on warning or speed signs were recorded mostly after participants started to decelerate. These findings suggest that drivers use information from the Focus of Expansion, be it a change in optical flow or the presence of a kink in the alignment, as the main cue to start decelerating. Parallel edges are also important cues, whereas warning and speed signs are primarily used to confirm that a speed change is needed.

1. Introduction

Freeways are designed to maintain a high speed throughout the trip, in accordance with drivers' expectations regarding operating speeds on freeways. At the same time, it is imperative that drivers anticipate any curves well in advance and reduce their speed to

* Corresponding author.

E-mail addresses: j.vos-1@tudelft.nl (J. Vos), j.c.f.dewinter@tudelft.nl (J. de Winter), h.farah@tudelft.nl (H. Farah), m.p.hagenzieker@tudelft.nl (M. Hagenzieker).

¹ ORCID: 0000-0001-5954-967X.

² ORCID: 0000-0002-1281-8200.

³ ORCID: 0000-0002-2919-0253.

⁴ ORCID: 0000-0002-5884-4877.

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navigate the curvy parts of the freeway safely. There is a lot of research on curve driving itself, both into speed behaviour (Malaghan, Pawar, & Dia, 2020; Vos & Farah, 2022) and perception (Lehtonen et al., 2018; Macuga, 2019), but driving task analysis (Campbell et al., 2012) shows that the anticipation of a curve starts far ahead of a curve and has considerable perceptual and cognitive requirements, i.e. where drivers look and how they judge this visual information. Freeways are considered to be self-explanatory (Theeuwes, 2021; Walker, Stanton, & Chowdhury, 2013), meaning that the driver knows when speed reduction is required based on a uniform road design. But there is limited research investigating which cues from the road design and environment drivers use to reduce their speed before a curve (Vos, Farah, & Hagenzieker, 2020). This research aims to gain insight into which visual information is used by the driver in curve approach and how this is related to deceleration before a curve.

Deceleration in curve approach has been modelled based on speed differences before and in the curve (Altamira, García Ramírez, Echaveguren, & Marcet, 2014; Hassan et al., 2011; Malaghan, Pawar, & Dia, 2021), but these models primarily use geometric elements as independent variables; attentional measures such as speed signs and warning signs are usually ignored. Moreover, deceleration models only reveal the amount of deceleration before a curve and not the position where deceleration starts (Vos & Farah, 2022), that is, the position where a driver starts to act towards the curve. Besides that the horizontal radius of the curve correlates to the position where a driver starts to slow down, Vos, Farah, and Hagenzieker (2021) showed that sight distances also correlate to this position, indicating the relevance of visual information the driver uses. Lehtonen, Lappi, Kotkanen, and Summala (2013) showed that during perceptual exploration of the road, a distinction could be made between guiding fixations and look-ahead fixations, which correspond, respectively, to the near and far points in the two-point steering model (Neumann & Deml, 2011; Salvucci, 2006). Guiding fixations are task-relevant fixations that precede action by about 1–2 s of driving (Mole, Pekkanen, Sheppard, Markkula, & Wilkie, 2021), whereas look-ahead fixations are fixations on objects relevant to future actions (Lehtonen et al., 2013; Mennie, Hayhoe, & Sullivan, 2007; Sullivan, Ludwig, Damen, Mayol-Cuevas, & Gilchrist, 2021). While driving on a tangent, the near point tends to be in the centre of the lane or on the car in front (Salvucci & Gray, 2004), and the far point is positioned on the horizon, where the lines in the environment seem to be still while the driver moves forward, that is, the point from which all optical flow vectors expand, also known as the Focus of Expansion after Gibson (1950). The guiding fixations in curve driving are usually aimed near the tangent point of the curve or the car ahead (Land & Lee, 1994; Lappi & Lehtonen, 2012; Shinar, McDowell, & Rockwell, 1977), and the look-ahead fixations are aimed more downstream in the curve towards what is identified as future point, far point (Lappi, 2014), or occlusion point (Lehtonen et al., 2013). The curve radius itself – which is highly correlated to the operating speed – is hard to perceive by drivers because it appears as a hyperbola on the retina due to its viewing angle (Brummelaar, 1975; Fildes & Triggs, 1985; Springer & Huizenga, 1975). Therefore, curve warning signs, special markings, and delineation are used to help the driver anticipate the curve correctly and choose a safe speed in the curve (Bella, 2013; Charlton, 2007; Costa, Figueira, & Larocca, 2022). This is in line with task descriptions of curve approach, which mention signs and visible road direction changes as indicators for curve anticipation (Campbell et al., 2012; McKnight & Adams, 1970). Drivers themselves indicate that a good view of the trajectory and the presence of guiding elements are important for choosing a suitable speed (Vos et al., 2020). It is however difficult for drivers to reflect on speed choices. That is because speed reduction during curve approach is an operational driving task (Michon, 1985) and is a skill-based process (Ranney, 1994) and therefore does not involve active thinking while driving. Speed reduction during curve approach can hence be described as subconscious. Charlton and Starkey (2011) showed that during unaware driving, correct motor responses are still produced. Similarly, in unaware locomotion, perceptual and cognitive processing is still present (Harms, van Dijken, Brookhuis, & de Waard, 2019). This research aims to gain insights in these perceptual and cognitive processes and identify the visual cues drivers use before and during deceleration while approaching a curve. To achieve this, two main research questions were formulated:

- Where do drivers look during curve approach, and how does this relate to deceleration?
- What do drivers report as important cues related to speed reduction during curve approach?

To investigate these research questions, an on-road study was conducted. A field study was chosen because a laboratory setting might disturb the unawareness of the driving behaviour (Shinar, 2017). Furthermore, road geometry in laboratory settings (e.g., driving simulators) might not be representative of the real world (Bobermin, Silva, & Ferreira, 2021). Familiarity with the test route may however bias the looking behaviour and driving speeds of local participants (Pratt, Geedipally, Dadashova, Wu, & Shirazi, 2019; Young, Mackenzie, Davies, & Crundall, 2018), so this was also tested. We used portable eye-tracking, concurrent think-aloud procedures, and GPS tracking — a combination that has been proven valuable in investigating information processing thanks to the complementarity of the methods (Kircher & Ahlstrom, 2018; Lenne, Salmon, & Young, 2011). Eye-tracking has been used in driving experiments for several decades and has contributed to our understanding of which visual information is used during driving processes (Crundall & Underwood, 2011). We focus on look-ahead fixations, since these are thought to reveal which cues are used to anticipate a curve. Concurrent think-aloud techniques can reveal in real-time what visual information drivers use to start an action (Read, Beanland, Lenné, Stanton, & Salmon, 2017), such as deceleration.

The following section, section 2, describes the methods of the experiment. The results are reported in section 3 and discussed in section 4. Finally, the main conclusions of this research are presented in section 5.

2. Methods

2.1. Participants

Thirty-one participants (5 female, 26 male) were recruited through the professional network of the first author and via the ANWB –

the Royal Dutch Touring Club. None of the participants wore glasses. Participants had to own and bring a passenger car and their driver's license. The research was approved by the Human Research Ethics Committee of the Delft University of Technology (letter of approval 1717). The participants had a mean age of 41.5 years ($SD = 13.3$ years) and a mean driving experience of 21.8 years ($SD = 13.2$ years). Most participants indicated being frequent drivers; only three indicated driving less than one day a week, while seven indicated driving every day. Participants were offered a €50 gift certificate for their time and car fuel.

2.2. Procedure

In order to capture how the participants interact with the road layout rather than other surrounding traffic, the experiment was carried out outside of peak hours in daylight settings, from 9:30 to 15:15.

Before the experiment, the participants were asked to sign an informed consent form and to fill in a NASA-TLX standardised test (Hart, 2006) regarding their drive to the location of the experiment. Next, the eye-tracker was calibrated, and the participant was asked to, during the experiment, reflect on their speed adaptations: *"I want you to explain to me why you change your speed during the drive on the freeway. Try to constantly answer the question 'how can you tell you need to slow down or speed up?'. In other words, please explain how you choose your speed. Please speak in your own words and drive like you normally would"*. By keeping the aim of verbalisation towards speed change in general, the participants were not biased towards curves. The participants then drove the route shown in Fig. 1, which lasted 33 min on average. During the drive, the participants wore the eye-tracker, and a portable GPS tracker was placed in the participants' car to record speed and position. The participants were asked to switch off their ADAS, as we were interested in speed reduction by the human driver and not by any autonomous system. The experimenter sat in the back seat of the car, giving route directions to the participant by orally mentioning the target direction (e.g. Amsterdam) on the upcoming route signage, keeping an eye on the recordings, and nudging the participant when deviating from the think-aloud protocol. After the experiment, the participants completed another NASA-TLX regarding their drive during the experiment. Furthermore, the participants were asked to rate their familiarity with each curve on a Likert-scale from 1 (not at all familiar) to 10 (very familiar) (Harms, Burdett, & Charlton, 2021) using a map, pictures of the road or help from the experimenter to identify the curves, and to reflect on the experiment in terms of how they experienced it and how they anticipated curves in a post-experiment questionnaire. During the experiment, all communication, including the think-aloud, was done in Dutch.

2.3. Test route

The test route was located on the freeways to the south of Amsterdam, had a length of 39 km, and included six curves of interest, see Fig. 1. The alignment of the curves was reconstructed in Civil3D using road measurements from the road authority to provide information about relevant geometric elements, such as the horizontal radii and the start of the continuous curve. The alignment starts at the position where the first route signage for the given direction is present and ends at the end of the connector road. The constructed alignment sections act as the scope of the data processing; data outside these sections was not processed.

Curve 1 is positioned after a two-lane deceleration lane. The curve itself remains obscured by a noise barrier that ends approximately 150 m upstream of the curve. The curve has a horizontal radius of 105 m. Just after the noise barrier, an advisory speed sign showing 50 km/h is positioned on the right shoulder. Curve 2 is the end of a main carriageway consisting of two lanes. It has a horizontal radius of 88 m. The curve is preceded by speed limit signs showing 80 km/h and 60 km/h and flashing warning signs at 700 m, 400 m, and 250 m upstream of the curve on both shoulders. Curve 3 is a direct connector road with a horizontal radius of 250 m. A



Fig. 1. The route participants drove and the selected six curves analysed in this study.

two-lane weaving section precedes this curve, and at the start of the curve, an advisory speed sign indicating 80 km/h is positioned on both shoulders. Curve 4a is preceded by a single lane split and a speed limit sign of 80 km/h positioned on the right shoulder of the curve. The curve has a horizontal radius of 360 m. The connector road continues with a curve and a tangent of approximately 1600 m consisting of two lanes. This is followed by Curve 4b with a horizontal radius of 128 m. The curve is mostly obscured by an overpass and preceded by advisory speed signs showing 50 km/h on both shoulders. Curve 5 is the shortest, with a length of 150 m and a horizontal radius of 300 m, and is preceded by a three-lane asymmetrical weaving section. The curve is not preceded by warning signs. Following Curve 5, signs are in place for the remainder of the connector road. Curves 4a, 4b, and 5 are followed by other curves, which are not analysed because the speed behaviour in these curves would be influenced by the preceding curves (Kim & Choi, 2013; Vos, 2022). Fig. 2 shows dashcam pictures at the approximate median positions where deceleration starts.

2.4. Data collection

The Qstarz BT-Q1000XT GPS-logger recorded the position and speed of the participants' car at a rate of 1 Hz and with a known accuracy of 78.7 % of the recorded location within 10 m of the expected location (Schipperijn et al., 2014). The Tobii Pro Glasses 3 records the participants' gaze data at 60 Hz and an HD video in the looking direction of the participant. The participants' verbalisations were also recorded by the Tobii Pro Glasses 3 in the HD video.



Fig. 2. Dashcam pictures at the approximate median positions where deceleration before each curve starts. Google maps locations via these hyperlinks: [Curve 1](#), [Curve 2](#), [Curve 3](#), [Curve 4a](#), [Curve 4b](#), [Curve 5](#).

2.5. Data analysis

2.5.1. GPS data

First, the GPS data points per participant were individually related to the closest position on the reconstructed alignment of the curves to have timestamps connected to specific positions along the alignment. Next, the acceleration profile was derived from the speed data by dividing the speed change in km/h every second by 3.6 to get acceleration in m/s^2 . Based on this acceleration profile, we were able to identify the last position upstream of the start of the curve where the participant maintained 0 m/s^2 . This position is illustrated in Fig. 3 and served as the position where the driver initiated action while approaching the curve, that is, the start of deceleration before the curve (Vos et al., 2021). Furthermore, based on the eye-tracking video, it was determined whether a participant was driving free-flow, i.e., having a minimum headway of 5 s (Hashim, 2011).

2.5.2. Fixation data

The analysis of the gaze data was done in the Tobii Pro Lab (Tobii Pro, 2021), which enables manual labelling of Areas of Interest. The software shows the percentage of gaze samples per participant. When this was below 80 %, it was analysed which individual curves had a coverage over 80 % and could therefore be included in the analysis. The raw data were compared with the pre-set filters in the software, and it was concluded that the “attention filter” showed the most meaningful results in our dynamic experimental environment. This filter maintains a gaze velocity threshold of 100 degrees/s, which allows for smooth pursuit (Bahill & LaRitz, 1984) and vestibular ocular reflexes (Schubert, Migliaccio, & Della Santina, 2006) to be captured as fixations. The software plots a fixation point halfway during the fixation length over the captured HD video. The visual size of the fixation point was chosen to be 1 % of the video height, increasing to a maximum of 5 % after a 1-s fixation duration. If a fixation point fell into an Area of Interest (AoI), it was manually labelled as belonging to that AoI.

For the applied labels, three types of fixations were identified, each corresponding to a number of AoIs:

- In-car fixations, with mirrors and the speedometer as AoI.
- Guiding fixations, which are fixations up to 2 driving seconds in front of the car and are used to guide the vehicle in the lateral position and keep distance (Lappi & Lehtonen, 2013). The corresponding AoIs included the centre of a lane, a car ahead, and tangent points.
- Look-ahead fixations, which are used to identify future actions (Lehtonen, Lappi, & Summala, 2012; Mennie et al., 2007). For the look-ahead fixations, the first author conducted a first round of labelling derived from the literature mentioned in the introduction. This led to several ambiguous labels, including overlapping ones, which were discussed among all authors. Based on this discussion, the authors defined a labelling hierarchy including three subgroups of AoIs relevant for look-ahead fixations:
 - o The first group of AoIs contained parallel edges to the curve. Using these parallel edges as a discriminatory element adheres to Gestalt grouping principles (Čičković, 2016; Geisler, Perry, Super, & Gallogly, 2001; Wagemans et al., 2012), which suggest that drivers heuristically use parallel edges to the actual curve, to anticipate the curve. Parallel edges were defined as solid edges that included noise barriers and guardrails, or more jagged edges, such as a treeline.
 - o If a fixation did not fall on a clear parallel edge, it was checked whether the fixation fell on objects that were either visually salient or carried information, namely, signs, gantries, or overpasses.
 - o If the fixation did not fall onto any of these objects, it was labelled based on one of several generic zones, namely, an occlusion point, far zone, the horizon, or the Focus of Expansion (Lehtonen et al., 2012). When a car ahead was further away than 2 s from the participant it was not considered a guiding fixation, but rather labelled according to the zone it is located in (e.g., FOE, Far zone, etc.).

Fig. 4 provides an overview of all AoIs in the hierarchy used during the labelling process; it illustrates that when a fixation overlaps two or more AoI's, the highest AoI in the hierarchy was selected. The full definitions of the corresponding labels are given in the Appendix. The labelling was done using the AoI tool in the Tobii Pro software. The AoI tool statically showed the defined labels as a snapshot and enabled the author to go along the video, fixation by fixation and label the correct AoI. The labelling was done by the first

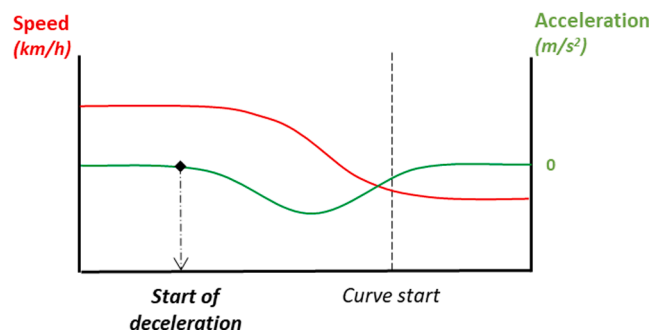


Fig. 3. Theoretical speed and acceleration profile showing the starting point of deceleration relative to the start of the curve.

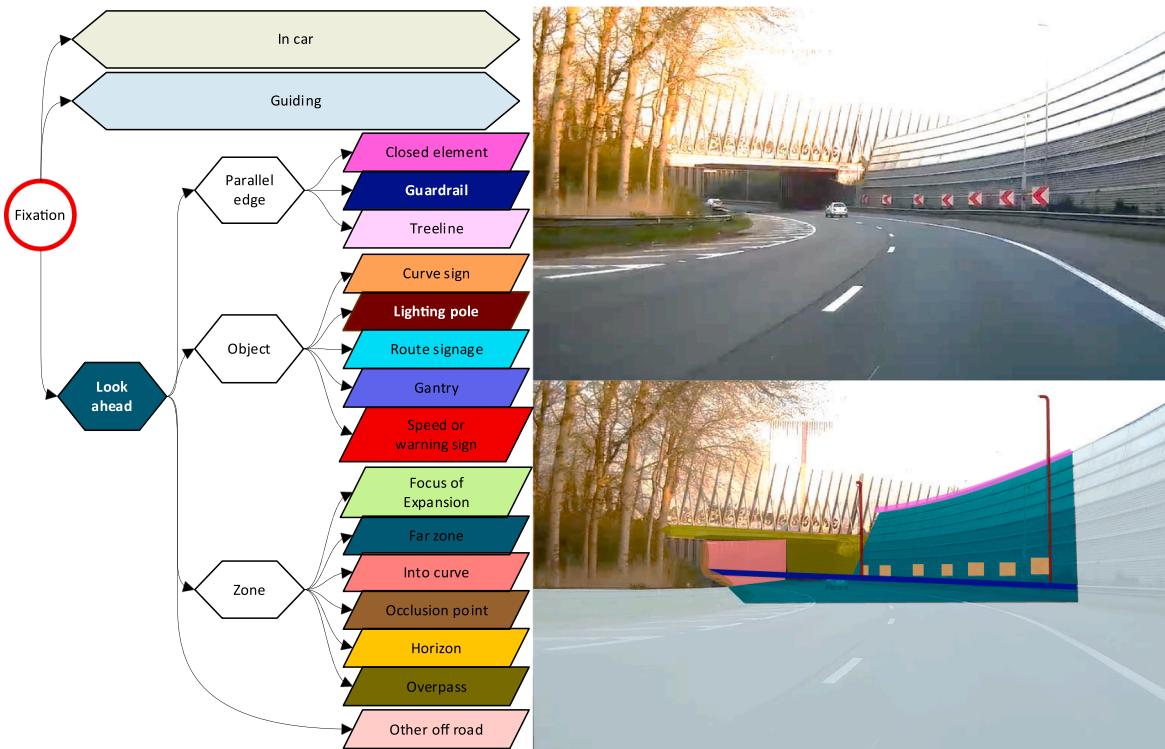


Fig. 4. Identified Areas of Interest in the labelling hierarchy. On the right, an example of a road view (top) and the corresponding Areas of Interest (bottom).

author. Because all fixations were labelled in this process, the reported distributions in the analysis section add up to 100 % of the measured fixations.

The timestamps of the fixations were matched with the timestamps from the GPS data. In this way, we were able to position the labelled fixation data both in space and time, that is, relative to the curve start and the start of the deceleration. The fixation durations per AoI were summed up per 50-m sections or per second for analysis in space or time, respectively, in line with the frequency of the GPS tracker, being 1 Hz, and given operational speeds of 30 m/s and an accuracy above 78 % within 10 m.

2.5.3. Verbal protocol analysis

The verbalisations were transcribed verbatim in Dutch and segmented based on mentioned subjects, pauses, or interactions with the experimenter. A segment is defined as a single identifiable unit being a reference, assertion, phrase, thought, or sentence. Each segment was individually labelled. Per segment, a timestamp and English labels were added heuristically by the first author to transform the verbal reports into data on time and subject (Hughes & Parkes, 2003). Additional labels were used per segment to reflect whether the verbal report was retrospective in nature and originated from long-term memory (Ericsson & Simon, 1980) and to reflect the level of driving task the verbal report related to (Michon, 1985). The retrospective segments were omitted from the analysis because these did not reflect the relevant driving task. Driving task levels were labelled “strategic” referring mostly for route choices, “tactical” referring mostly for lane changes, and “operational” referring mostly for speed adjustments. The heuristic labels were discussed among all the authors, focusing on labels deemed ambiguous. The discussion resulted in a detailed description of the labels shown in the Appendix. Based on this detailed description, the first author altered the ambiguous labels accordingly. The following label groups were distinguished:

- Driver-related: reporting on the driving style, operating or maximum speed, familiarity, or comfort.
- Traffic-related: reporting on the traffic surrounding the participant or how the participant interacted with traffic.
- Speed adjustments related to the curve: reporting on decelerating upstream of the curve or accelerating out of the curve.
- Curve-related: reporting on curve sighting, anticipation, and signs.
- Other cues: reporting on the general characteristics of the road and its environment; these could be cues for curves, such as the type of road, number of lanes, or route signage.
- Non-speed-related: a residual group used to label all non-speed-related verbal reports.

Examples of verbal feedback in this paper were translated into English by the first author.

3. Results

3.1. Task load

The results of the NASA-TLX task load scores before and after the experiment were compared to assess the difference in task loads between normal driving (i.e., driving to arrive at the experiment location) and driving during this experiment. Temporal demand during normal driving (median = 25, $SD = 21$) was significantly higher, $t(30) = 3.16$, $p = 0.004$, than the temporal demand during the experiment (median = 10, $SD = 14$). According to six participants, the setting of the experiment was more relaxed compared to the normally rushed driving on a freeway, which could explain the above difference in temporal demand. The effort during the experiment (median = 20, $SD = 17$) was significantly higher, $t(30) = -2.29$, $p = 0.029$, than the effort during normal freeway driving (median 15, $SD = 11$). Five participants mentioned the extra effort of wearing the eye-tracker during the experiment. No significant differences were observed in mental demand, physical demand, performance, or frustration between normal driving and driving during the experiment.

3.2. Fixation duration

The eye-tracker recordings of one participant were not saved correctly, one participant appeared to be near-sighted, and two calibrations were questionable. The entire measurements from these four participants were omitted from the database. The remaining 27 measurements were further analysed. During the experiment several days were rather sunny. The sun interferes with the infrared illuminators of the eye-tracker, resulting in poor eye-tracking or no measurements at all because of squinting eyes in several individual curves per participant. These individual curves were omitted from the database. All of the above resulted in 22 successful recordings for Curves 1 and 4b, 21 successful recordings for Curve 2, and 23 successful recordings for Curves 3, 4a, and 5.

The median fixation duration of all fixations was 240 ms ($SD = 557$ ms). In-car fixations, guiding fixations, and look-ahead fixations had a median duration of 240 ms ($SD = 208$ ms), 281 ms ($SD = 624$ ms), and 220 ms ($SD = 575$ ms), respectively.

3.2.1. Distribution of fixation duration towards curve start

The distribution of fixation duration of all participants and curves from 550 m before to 250 m after the curve start is shown in Fig. 5. The participants spent about 40 % of the time on look-ahead fixations in the curve approach and curve entry. A Wilcoxon signed-rank test indicated that the number of look-ahead fixations 550 m before the start of the curve (median = 40 %) and 150 m after the start of the curve (median = 36 %) was not statistically significantly different ($p = 0.222$, $r = 0.106$); for this comparison, 150 m was used, as for the shortest curve (Curve 5) fixations beyond that point could also be assigned to tangents or curve approach of a second curve.

Fig. 6 zooms in on the distribution of look-ahead fixations around the start of the curve. A transition zone between 300 m and 100 m upstream of the curve is visible, where fixations shifted from the Focus of Expansion, route signage, and speed or warning signs to the far zone, parallel edges (closed elements, guardrail, and treelines parallel to the curve), and curve signs.

3.2.2. Distribution of fixation duration towards deceleration

Fig. 7 shows the distribution of fixation durations from 20 s before to 20 s after the participants started to decelerate. No change in look-ahead fixations is observed before, around, or after the start of deceleration. A Wilcoxon signed-rank test indicated that the number of look-ahead fixations 20 s before the start of deceleration (median = 39 %) and 20 s after the start of deceleration (median = 46 %) was not statistically significantly different ($p = 0.951$, $r = 0.006$).

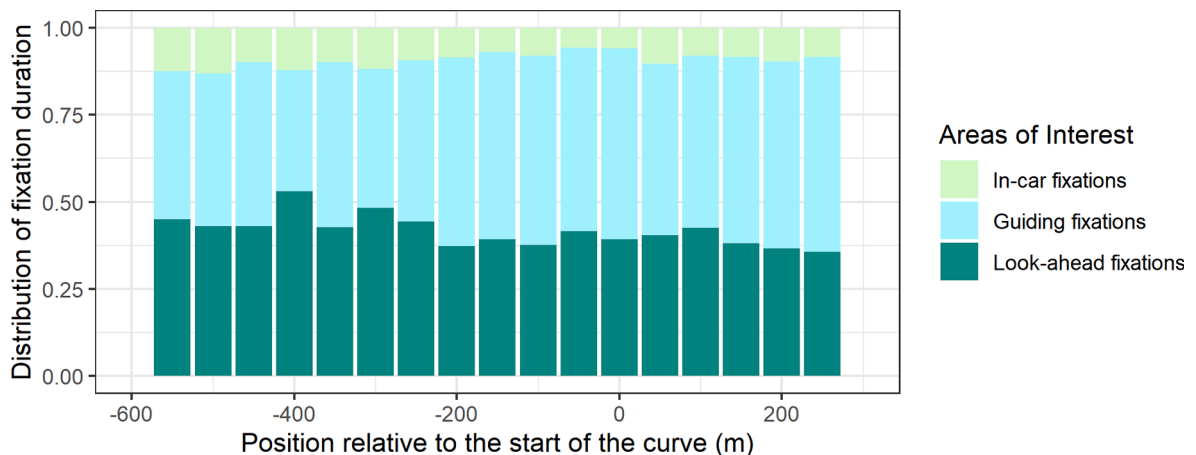


Fig. 5. Distribution of fixation duration of all curves and all participants relative to the start of the curve.

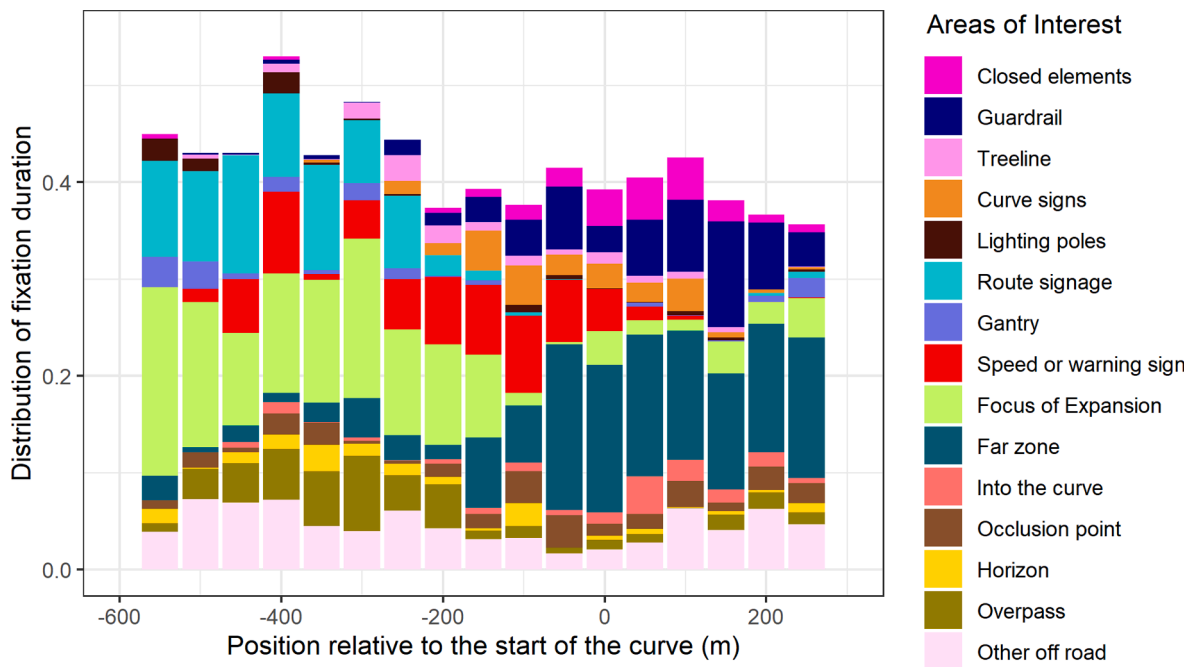


Fig. 6. Distribution of fixation duration for look-ahead fixations of all curves and all participants, relative to the start of the curve.

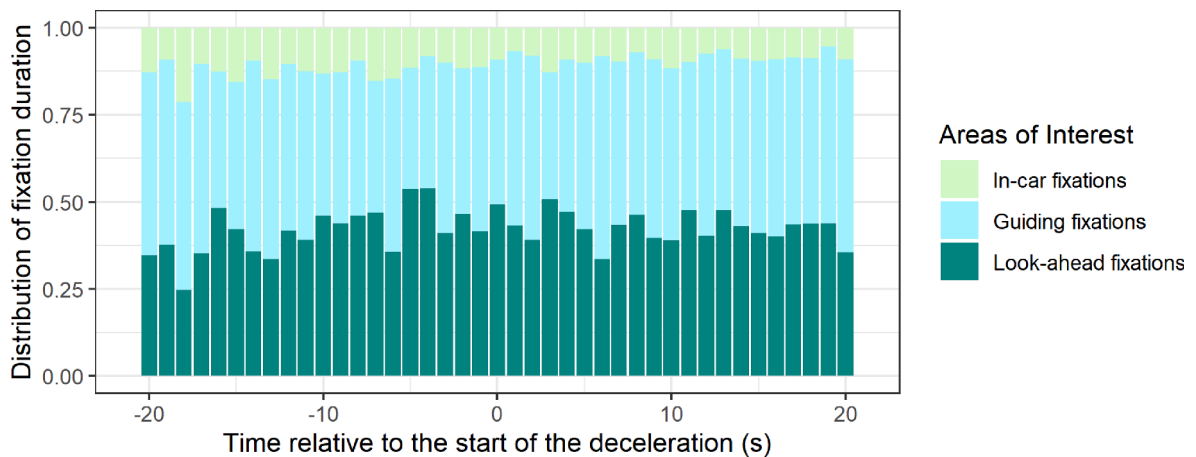


Fig. 7. Distribution of fixation duration of all curves and all participants, relative to the start of deceleration.

Fig. 8 zooms in on the distribution of look-ahead fixations around the start of deceleration. Until about 3 s prior to the start of deceleration, participants focused mainly on the Focus of Expansion and route signage. The latter might be due to the experimental setup, where the experimenter pointed out route signage for route directions. A small increase in fixations on the Focus of Expansion is seen 4 s before the start of deceleration. Furthermore, it is noticed that when drivers started to decelerate, they fixated less on the Focus of Expansion and more on the far zone and parallel edges (closed elements, guardrail, and treelines parallel to the curve). An increase in fixations on speed signs or warning signs is only noticeable after the deceleration has started.

3.2.3. Distribution of fixation duration in individual curves

Each of the investigated curves had a unique layout; therefore, unique driving behaviour was expected. An average speed profile of all participants, the fixation duration, and the start of deceleration distribution per curve are shown in individual figures.

Curve 1 shows in Fig. 9 a rather sudden change in look-ahead fixations around 200 m before the curve. This is likely due to the end of the noise barrier, which obstructed the view towards the speed sign and the far zone of the curve itself. Participants showed more interest in the occlusion point in Curve 1 than in the other curves. Most participants started to decelerate before fixating on the speed sign.

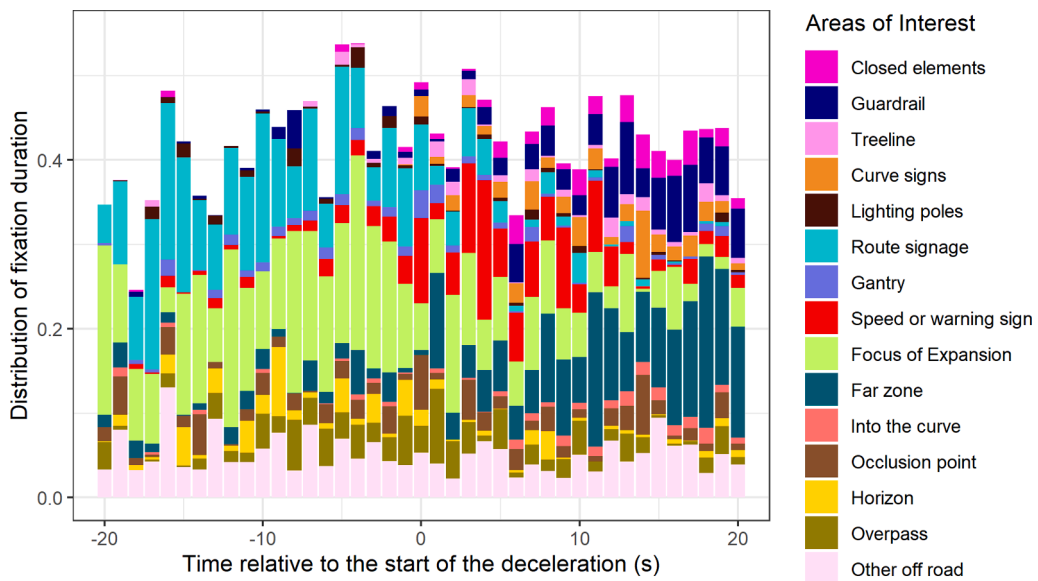


Fig. 8. Distribution of fixation duration for look-ahead fixations of all curves and all participants, relative to the start of deceleration.

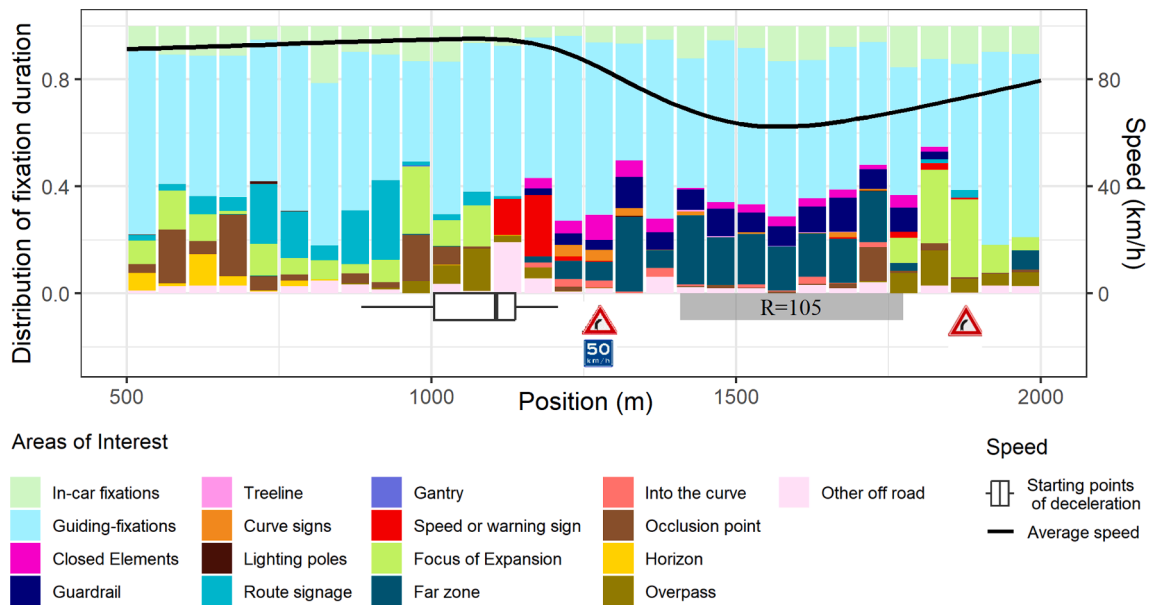


Fig. 9. Average speed behaviour, distribution of fixation duration, and start of deceleration distribution of Curve 1, having a horizontal radius of 105 m. The positions of the curve is indicated with a grey box and the positions of speed and warning signs are also indicated.

Curve 2 was positioned at the end of a main carriageway; therefore, there were many speed and warning signs present before the curve, since such a sharp curve is not expected in a main carriageway. As seen in Fig. 10, most participants started to decelerate after fixating on the first speed and warning sign. At the positions where most decelerations started, an equal amount of time was dedicated to the warning signs and the Focus of Expansion. Only after the deceleration started participants fixated on the parallel edges or the far zone.

Curve 3 shows in Fig. 11 an increase in fixation towards the Focus of Expansion and the warning signs just before most participants started to decelerate. After the deceleration started, the attention shifted towards the occlusion point, far zone, and less towards the focus of expansion. The warning sign on Curve 3 is located just in front of the overpass, obstructing most of the curve. Since only guardrails are present as a parallel edge, not many fixations are given on parallel edges, but more on the far zone.

Curve 4a shows in Fig. 12 that most participants started to decelerate before fixating on the speed sign. A few look-ahead fixations towards a far zone were observed because this curve was clearly in sight and moved over the main carriageway. Curve 4b shows in

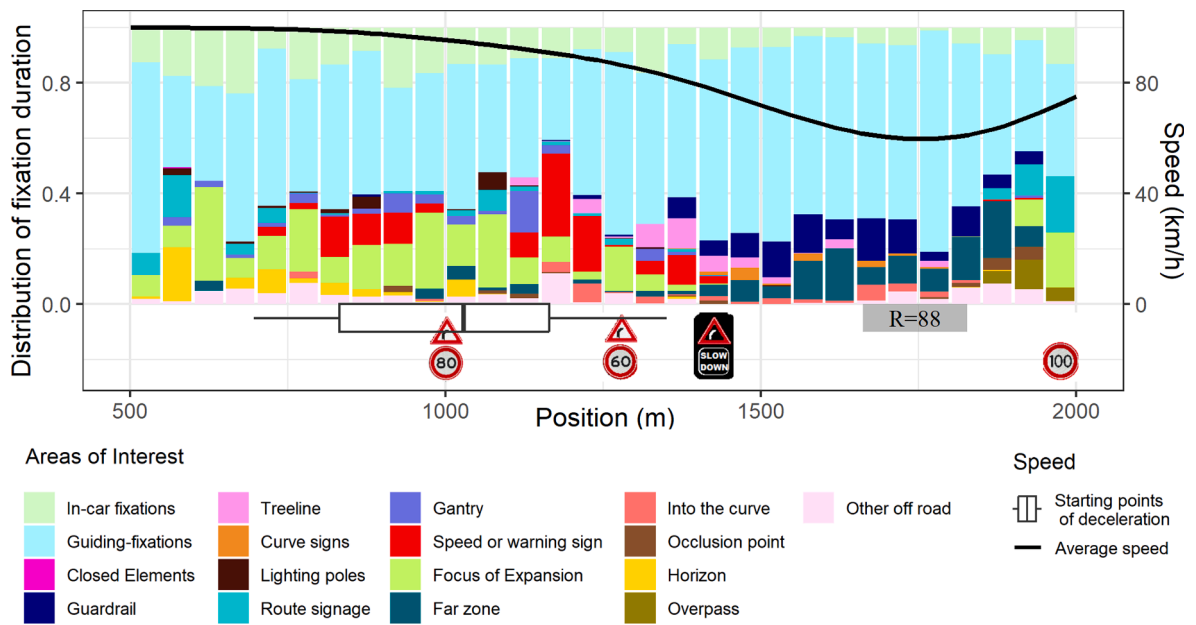


Fig. 10. Average speed behaviour, distribution of fixation duration, and start of deceleration distribution of Curve 2, having a horizontal radius of 88 m. The positions of the curve is indicated with a grey box and the positions of speed and warning signs are also indicated.

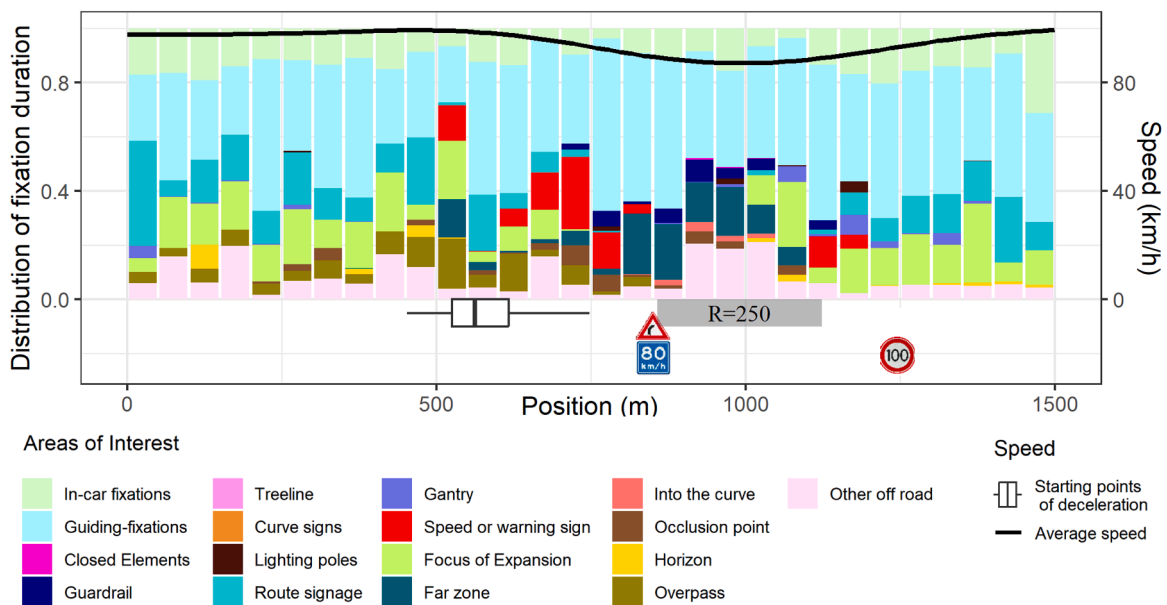


Fig. 11. Average speed behaviour, distribution of fixation duration, and start of deceleration distribution of Curve 3 having a horizontal radius of 250 m. The positions of the curve is indicated with a grey box and the positions of speed and warning signs are also indicated.

Fig. 13 an increase of fixations towards the warning sign before most participants started to decelerate. Only after starting to decelerate the curve signs (chevrons) were fixated on. Again, this curve was mostly obscured by an overpass.

Curve 5 was the first, short, curve of a set of curves in a junction. Deceleration before these curves was preceded only by fixations towards the Focus of Expansion and route signage, as showed in Fig. 14. No warning signs were present before the first curve to fixate upon.

3.2.4. Effects of familiarity

The participants scored their familiarity in Curve 1 on average 4.8 ($SD = 3.1$), in Curve 2 on average 5.6 ($SD = 3.6$), in Curve 3 on

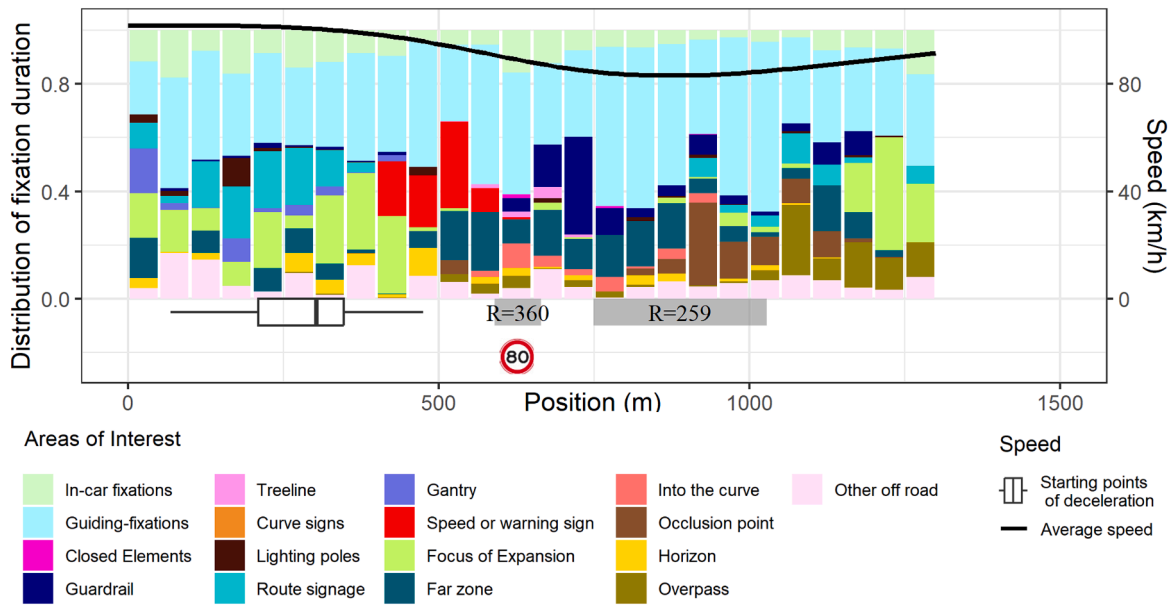


Fig. 12. Average speed behaviour, distribution of fixation duration, and start of deceleration distribution of Curve 4a, having a horizontal radius of 360 m. The positions of the curve is indicated with a grey box and the positions of speed and warning signs are also indicated.

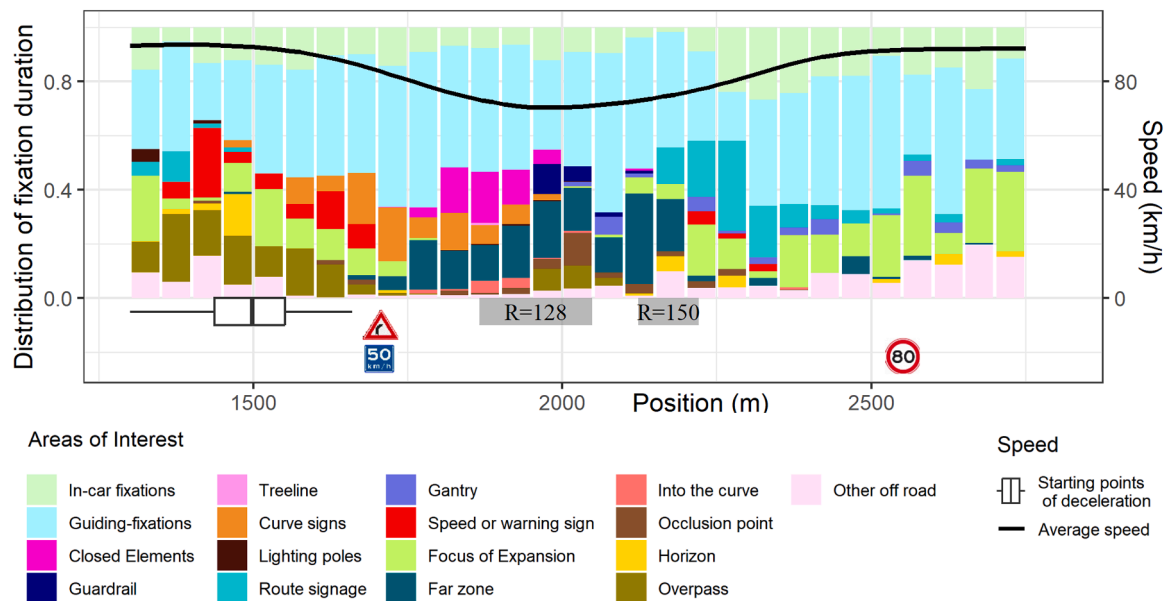


Fig. 13. Average speed behaviour, distribution of fixation duration, and start of deceleration distribution of Curve 4b, having a horizontal radius of 128 m. The positions of the curve is indicated with a grey box and the positions of speed and warning signs are also indicated.

average 5.4 ($SD = 3.1$), in Curve 4a and 4b on average 3.1 ($SD = 2.6$) and in Curve 5 on average 5.7 ($SD = 3.3$). Familiarity was not correlated to the position where participants in free-flow situations started to decelerate. Familiarity showed however weak positive relationships with speed at curve start in free-flow situations. Pearson's correlation coefficients ranging from $r(10) = 0.03, p = 0.91$ in Curve 5 to $r(25) = 0.46, p = 0.02$ in Curve 4a indicate higher speeds with higher familiarity of a curve. For each participant, the relative amount of fixation duration towards specific Areas of Interest were tested on correlation. Familiarity has a weak negative relationship to the relative look-ahead fixation duration ($r(22) = -0.32, p = 0.13$), and a negative relationship towards the relative fixation duration towards parallel edges (closed elements, guardrails and tree lines) ($r(22) = -0.36, p = 0.08$). There was no relationship between Familiarity, on the one hand, and fixations on curve signs, speed/warning signs, Focus of Expansion, or the far zone, on the other.

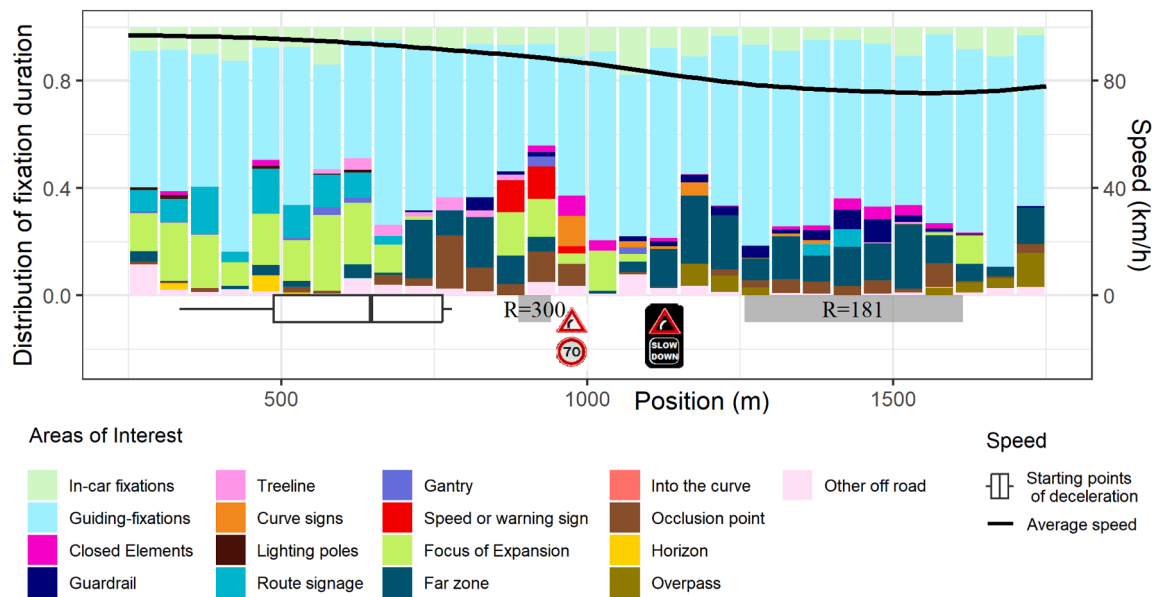


Fig. 14. Average speed behaviour, distribution of fixation duration, and start of deceleration distribution of Curve 5, having a horizontal radius of 300 m. The positions of the curve is indicated with a grey box and the positions of speed and warning signs are also indicated.

3.3. Verbalisation

The participants were verbalising their operational driving task on average 22 % ($SD = 19$ %) of the total time while driving on the sections of the road investigated. Verbalising the tactical and strategic driving tasks took up on average 4 % ($SD = 7$ %) and 4 % ($SD = 5$ %) of the driving time respectively, while on average 10 % ($SD = 16$ %) of the time was spent verbalising on non-driving task topics. For each of the labels defined in the Appendix, Table 1 shows how many times each topic was verbalised. In total, 1301 verbalisation

Table 1

Summary of verbalisations related to speed. In bold, the group totals, and bullet-wise the individual labels are shown.

	%	N		%	N
Driver-related	23.1 %	300	Curve-related	11.7 %	152
• Driving style	5.5 %	72	• Curve sighting	5.1 %	67
• Operating speed	3.5 %	46	• Anticipating radius	5.1 %	66
• Faster than speed sign	4.5 %	60	• Anticipating length	0.7 %	9
• Slower than speed sign	0.2 %	3	• Curve direction	1.2 %	15
• Unsure about max speed	0.5 %	6	• Curve end	0.3 %	4
• Comfort	4.6 %	63	• Oversight	0.8 %	10
• Familiarity	5.7 %	75	• No oversight	0.9 %	12
			• Speed sign	8.4 %	109
			• Trees	0.0 %	0
			• Warning sign	0.7 %	9
			• Curve sign (chevron)	0.2 %	2
Traffic-related	20.3 %	265	Other cues	2.9 %	38
• Cars braking	1.8 %	23	• Type of road	1.2 %	15
• Traffic volume	2.0 %	26	• Number of lanes	0.6 %	8
• Adjust to traffic	9.0 %	117	• Lane ending	0.8 %	10
• Overtaking	3.8 %	50	• Special marking	0.0 %	0
• Pre-sorting	4.3 %	56	• Route signing	0.5 %	6
• Lane-keeping	0.4 %	5	• Overpass	0.0 %	0
Speed-related to curve	18.9 %	246	Not related to external speed cues	26.4 %	343
• Decelerating for curve	12.8 %	167			
• Accelerating after curve	6.2 %	81			

segments were labelled. Since each segment can have multiple labels, the percentages given in Table 1 reflect the percentage of segments containing these labels. A large number of verbalisations were related to the driver and surrounding traffic, and only about 30 % of the verbalisations were related to the curve. Out of the verbalisations related to the curve, most were on decelerating for the curve.

Some participants mentioned that it was hard to verbalise the anticipation of a curve because it is such a natural or logical thing to do. Participant 1 said, for example: *“I’m reducing speed for a curve, but that goes without saying, right?”*.

3.3.1. Co-occurrence with deceleration

As seen in Table 1, decelerating for a curve was mentioned 167 times during the experiment. Sometimes the participant elaborated further on the specific cue or reason, which led to multiple assigned labels per segment (co-occurrence in labels). Since the aim of this research is to understand which cues drivers use to decelerate, co-occurrence with the verbalisation of decelerations is further researched. Table 2 shows the distribution among the different labels that co-occurred with the label of deceleration for a curve in a single verbalisation segment. Out of the 167 verbalisations of deceleration for a curve, 92 did not co-occur with other labels (55 %) and gave, therefore, no specific cue for deceleration for a curve. Table 2 shows the distribution of the remaining 45 % of verbalisations.

Table 2 shows that most of the co-occurring labels with “decelerating for a curve” were towards speed signs, seeing the curve itself, and anticipating its radius. In addition to the reasons mentioned in Table 2, two participants elaborated in retrospective verbalisations on using on-board navigation systems with a map to anticipate an upcoming curve.

3.3.2. Sign verbalisation

Table 1 shows that speed signs were verbalised ten times more than warning signs and that curve chevron signs were seldom mentioned. Warning sign labels co-occurred in a verbalisation segment only once with a curve sighting label and three times with a speed sign label. Speed sign labels co-occurred four times with curve sighting labels, and warning sign labels co-occurred only once with curve sighting labels. A number of participants verbalised speed signs just after verbalising curve discovery:

- *“I’m decelerating because I see an upcoming curve, would have done that even without the speed sign”* (Participant 1)
- *“A sharp curve here, designated with a 80 km/h sign and a warning sign”* (participant 5)
- *“I don’t want to drive too fast with this upcoming curve. And indeed, a warning sign “you are driving too fast”, so... I’m going to adjust my speed to the other traffic”* (Participant 11)
- *“But this is a curve with an advisory speed of 50 km/h, so I’m going to brake harder”* (Participant 25)

Verbalisations of speed signs both mention following up the speed on the sign and not. A couple of examples are:

- *“80 km/h, but I’m driving 100 km/h still, so I’m driving a bit too fast, but this is well suited for 100 km/h”* (Participant 5)
- *“I’m seeing a sign 70 km/h, I think, well, let’s release gas.”* (Participant 8)
- *“I’ve seen the advisory speed sign 80 km/h but chose not to comply because it’s wide enough, sunny and the road surface looks good”.* (Participant 11)

Table 2

Co-occurring labels along verbalising “decelerating for a curve”. In bold, the group totals, and bullet-wise the individual labels are shown.

	%	n
Driver-related	10.2 %	17
• Driving style	1.2 %	2
• Operating speed	0.6 %	1
• Faster than speed sign	1.2 %	2
• Comfort	4.8 %	8
• Familiarity	2.4 %	4
Traffic-related	3.6 %	6
• Cars braking	1.8 %	3
• Adjusting to traffic	1.2 %	2
• Overtaking	0.6 %	1
Curve-related	34.1 %	57
• Curve sighting	12.0 %	20
• Anticipating radius	11.4 %	19
• Anticipating length	0.6 %	1
• Curve direction	0.6 %	1
• No oversight	1.8 %	3
• Speed sign	13.2 %	22
Other cues	0.6 %	1
• Road type	0.6 %	1

- “Well, we’re allowed 80 km/h and approaching with 120 km/h. That curve is perfectly suited for 110 km/h. I don’t understand that sign”. (Participant 15)
- “Oh, there it becomes 50 km/h, so, let’s slow down.” (Participant 17)
- “Advisory speed 50 km/h. Let’s see what my predecessors do. They don’t brake a lot, so I think 70 km/h is a nice speed. A sharp curve, so I’m slowing down. This is a good speed.” (Participant 20)
- “I see 50 km/h here, so, eh. Advisory speed, so let’s adhere to that”. (Participant 23)
- “I’m releasing gas now; it said 80 km/h”. (Participant 28)

No specific verbalisations towards the use of the Focus of Expansion, parallel edges, or far zones are given.

3.4. Participant feedback on speed reduction before curve

After revealing the aim of the experiment in the post-experiment questionnaire, several participants shared their insights into how they reduced speed before a curve in the final questionnaire. Four participants mentioned that all curves had different signs, but only three others shared that they did use signs to anticipate their speed. Participant 4 actually shared a description of curve approach: “I follow the traffic in front of me. I reduce speed upon seeing a speed sign. In a regular situation, I tend to brake as less as possible. I then judge the curve on sharpness, clarity, traffic volume and speed”. Overall, 20 participants could not give insights into how they reduce speed before a curve in the post-experiment questionnaire, indicating unawareness.

4. Discussion and limitations

The main aim of this research was to gain insights into which visual cues drivers use to reduce speed upon approaching a curve. By combining speed data and look ahead-fixations, we found that the participants tended to start decelerating about 4 s after look-ahead fixations on the Focus of Expansion increased and that fixations on speed and warning signs are mostly manifested after the start of deceleration. Towards the curve start, fixations towards parallel edges (closed elements, guardrail or treelines parallel to the curve trajectory) and into the curve itself are increased, and fixations on the Focus of Expansion are decreased. These findings deviate from driving task descriptions (Campbell et al., 2012; McKnight & Adams, 1970), which position the gathering of speed information from signing at the same time of initial speed reduction and as one of the primary speed influences. We conclude that the curve discovery on the Focus of Expansion itself provides enough visual information to start reducing speed. We therefore diminish the usually suggested importance of signs for curve anticipation (Borowsky, Shinar, & Parmet, 2008; Campbell et al., 2012; Costa et al., 2022; Fitzpatrick, Carlson, Brewer, & Wooldridge, 2003; Montella, Galante, Mauriello, & Pariota, 2015). Verbal feedback confirmed that speed signs are used to assess the needed speed reduction better, knowing that the speed indicated on the signs can usually be exceeded. This non-compliance is in line with Ahie, Charlton, and Starkey (2015).

The reported large amount of fixations on the Focus of Expansion on tangents are in line with previous research (Lehtonen et al., 2012; Salvucci & Gray, 2004; Shinar et al., 1977). The increased amount of fixations on the Focus of Expansion before the start of deceleration might indicate that participants used a change in the optical flow near the Focus of Expansion (Rogers, 2021) or the presence of a kink in the road trajectory (Brummelaar, 1975) as a first indicator of the curve itself, which is in line with Gestalt grouping principles (Čičković, 2016). No verbal reports on this first curve discovery were made, suggesting highly automated responses. Similarly, most participants could not actively answer the post-experiment question on their speed-adjusting behaviour in curve approach, underpinning the unawareness and skill-based nature of this driving task. Towards the start of the curve, fixations on the Focus of Expansion diminished in favour of fixations on parallel edges and the far zone, not being the occlusion point per se (Lehtonen et al., 2012), suggesting that the participants anticipated the curve sharpness mostly based on the available information in their field of view. We furthermore found a fairly stable amount of look-ahead fixations of 39–44 % of the time during curve approach, while earlier research reported 10–33 % (Lehtonen et al., 2013). This difference might be because Lehtonen et al. (2013) defined look-ahead fixations as being outside the 6-degrees field of view, while we labelled it based on the contents in the Area of Interest.

A large proportion of verbal reporting was devoted to speed signs, which might be due to the task to verbalise speed behaviour. Curve 2, however, demonstrates how warning signs are used as the main cue to start deceleration when the curve is in the main carriageway, on which no such sharp curve is expected, while there are no good parallel edges available. The large amount of fixations on the route signage reported might be due to the experimental setup, where the experimenter gave route directions orally by pointing out directions on the route signage.

Familiarity of participants with specific curves, resulted in higher speeds, which is in line with the finding by Pratt et al. (2019). Furthermore, familiarity of curves led to less time spent on look ahead fixations in general and towards parallel edges (closed elements, guardrails and tree lines) in general. These findings are in line with findings by Young et al. (2018), showing more fixations on the road far ahead with less familiarity. Only 16 % of the participants were female, so our results may be skewed towards male speed and fixation behaviour.

Think-aloud methods might interfere with natural driving behaviour (Salmon et al., 2017; Thomas, Goode, Grant, Taylor, &

Salmon, 2015) or looking behaviour (Prokop, Pilař, & Tichá, 2020) and might make participants more aware than they would be in everyday driving. To investigate the effect of the think-aloud protocol on the participants' behaviour, a pilot study was conducted prior to the experiment in which four test participants (2 male, 2 female, average age of 45 years, average amount of driving experience of 24 years) drove the proposed route twice. On the first drive, two participants were asked to engage in concurrent think-aloud, and the other two were asked to drive without concurrent think-aloud. The second drive was vice versa. Comparing the collected data from sessions with and without concurrent think-aloud did not show major differences in speed, deceleration, fixation lengths or distribution. Therefore, concurrent think-aloud was applied to understand which visual cues were used by the participants to reduce speed (Ericsson & Fox, 2011). Retrospective think-aloud might have given more insights (Stapel, El Hassnaoui, & Happee, 2020) than concurrent think-aloud, but it would not be possible to stop on a freeway, and memory decays after two minutes. The task-load comparison between pre-experiment and post experiment, and the post-experiment questionnaire did not show signs that the verbalisation interfered with the natural driving task.

Eye-tracking does not provide information on the role of peripheral vision in anticipating speed (Martens, Comte, & Kaptein, 1997) and in helping to focus on relevant information (Wolfe, Sawyer, & Rosenholtz, 2022). It can, however, be argued that the relevant visual information is attended to with a fixation on the fovea (Crundall & Underwood, 2011). Furthermore, our research focusses on look-ahead fixations, which generally are not in the periphery but at least 50 m and up to 500 m in front of the driver. At the same time, these large distances are a downside in this research, as at such distances, the HD video does not show details that the human eye might perceive, making the labelling of Areas of Interest ambiguous. Therefore, labels at the horizon, Focus of Expansion, or far zone might have been overrepresented in this research.

5. Conclusions and implications

By using three different methodologies, GPS, eye-tracking, and think-aloud, we were able to gain insights into which visual cues drivers use to reduce speed upon approaching a freeway curve. We used the qualitative data gathered from the verbal protocol to support and interpret the quantitative analysis from GPS and eye-tracking.

The results showed that participants used the Focus of Expansion and parallel edges as a first cue to start decelerating before a curve. When this visual information was not sufficiently available participants used warning and speed signs as a first cue. Speed signs were generally used in a confirmatory manner or to update speed anticipation.

The results support the self-explaining nature of freeways and imply that when deceleration is needed based on the geometric design, extra attention should be paid to the road layout and its surrounding so that it provides enough information to the drivers about an upcoming curve. This could be done by using parallel edges. Speed and warning signs can be used when the road layout is unclear, such as when parallel edges are obstructed or absent. Further research is needed to understand the situations in which extra signs are needed and on which exact position to place them, to match the expectations of drivers.

CRediT authorship contribution statement

Johan Vos: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization, Project administration, Funding acquisition. **Joost de Winter:** Conceptualization, Methodology, Validation, Writing – review & editing. **Haneen Farah:** Conceptualization, Validation, Writing – review & editing, Supervision. **Marjan Hagenzieker:** Validation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability






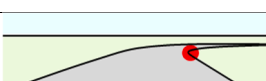

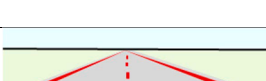

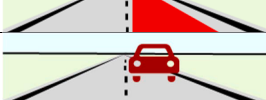
The research data is available at 4TU.ResearchData: <https://doi.org/10.4121/21069820>.

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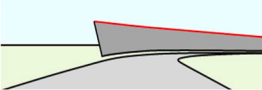
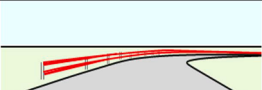
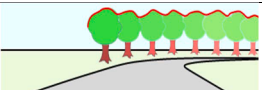

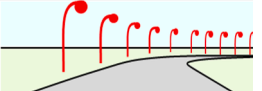









Appendix A – Labels

Areas of Interest

Aol	Definition	Picture
In-Car		
Speedometer	The area on the dashboard where the driven speed is shown	
Rear-view mirror	The mirror positioned inside the car to look through the rear window	
Side-view mirror LEFT	External wing mirror on the left side of the car, used to look to the left side behind the car	
Side-view mirror RIGHT	External wing mirror on the right side of the car, used to look to the right side behind the car	
Other	Such as radio, gear-shift, navigation, or body of the car	
Guiding fixations		
Lane tangent point	Any inside curve road marking on tangent point (either closed, open, or block marking). Recognisable as an edge	
Road edge tangent point	Inside curve edge of pavement or crown line (earthworks). Recognisable as an edge	
Obstacle inside curve	Any obstacle located at the inside of a curve, such as guardrail, noise barriers, trees, or bushes which either obscures the sight through a curve or guides the driver	
Marking	All types of marking on the edge of lanes, including noses (not located at the Tangent Point). Recognisable as an edge	
Centre of lane	Including arrow markings	
Car ahead	A car ahead in any lane in front of the participant. When the car is further away than 2 seconds from the driver, it is assumed not to be a guiding fixation, but it is labelled according to the zone the car is located in.	

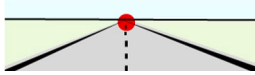
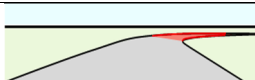

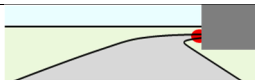


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Look ahead fixations		
Parallel edges		
Closed elements on the outside of a curve	Such as noise barriers (smooth and straight) Gaze point overlaps with a recognisable edge, so at least with the top of the element or another clear edge within the element	
Guardrail on the outside of a curve	Guardrail or barrier Gaze point overlaps with one of the clearly recognisable edges	
Treeline on the outside of a curve	A wall created by nature; rugged but mainly parallel to the roadway	
Aol	Definition	Picture
	Gaze point overlaps with the top of the treeline, which is recognisable as an edge.	
Objects		
Curve signs (chevron) outside of a curve	A part of this sign is within the gaze point	
Lighting poles	Either inside or outside the curve A part of a lighting pole is within the gaze point	
Route signage	A part of this sign is within the gaze point	
Gantry	The supporting structure for road signs A part of the gantry is within the gaze point	
Curve warning sign	A part of this sign is within the gaze point	
Curve warning sign (DYNAMIC)	A part of this sign is within the gaze point	
Speed sign (MAX)	A part of this sign is within the gaze point	
Speed sign (MAX) incl curve warning	A part of this sign is within the gaze point	 
Speed sign (ADVICE) incl curve warning	A part of this sign is within the gaze point	 

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Aol	Definition	Picture
Zones		
Focus of Expansion	On a tangent, the position where the road disappears on the horizon. In a curve, the position where the optical flow originates from The gaze point is located at this clear, single point, not being an occlusion point	
Far zone (future path)	Patch of road beyond the tangent point, not clearly defined by parallel edges. The road itself is, however, still clearly distinguishable. The gaze point is on the road, beyond the tangent point	
Into curve	Road section not directly visible, beyond the far zone. So, the contours suggest the curve is going there, but no clear edges are recognisable The gaze point is on a surface, not containing edges, beyond the far zone, suggesting the trajectory of the road	
Occlusion point	Point where the roadway disappears. Often being obscured by a vertical element (occlusion point trumps the vertical occluding element in labelling) The gaze point is in the position where the roadway clearly disappears behind a vertical element.	
Horizon	Fixations on the horizon, other than on the Focus of Expansion	
Overpass ahead	All distinguishable parts of an overpass: girders, columns	
Aol	Definition	Picture
Other off road		
Other off road	Everything else, e.g., advertisements, buildings, trains, sky	

Verbalisation

Label	Definition	Example verbalisations
Driver-related		
Driving style	General mentions about driving style of the participant	<p>I like to go fast through a curve</p> <p>Being (anti)social</p> <p>Having room to manoeuvre</p> <p>It's fun to drive (fast), and I want to accelerate fast</p> <p>Careful when driving and approaching curves</p>

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Label	Definition	Example verbalisations
Operating speed	Explicitly mentioning the current operating speed by reading out the speedometer	I'm driving 78 now
Faster than speed sign	Relating the current operating speed to the maximum (or advised) operating speed when the participant is going faster	I'm driving a bit faster now than 80 Usually you can drive faster through a curve
Slower than speed sign	Relating the current operating speed to the maximum (or advised) operating speed when the participant is going slower	I'm allowed to go faster
Unsure about max speed	Stating unawareness about the applicable maximum operating speed	Does this 80 still apply here? I'm looking for speed information
Comfort	Statements about the comfort of driving through the present (or upcoming) curve. This includes relations with lateral acceleration (speed in relation to radius) and drivability.	Adjusting speed for a comfortable drive (I'm braking a bit more) Pre-adjusting speed in order not to brake in the curve This is a nice speed in the curve This feels nice
Familiarity	Statements about the familiarity of the present or upcoming stretch of roadway	I know this stretch very well I usually go to the right here I've never been here before
Traffic-related		
Cars braking	Statements of braking cars downstream of the participant	Cars ahead are braking / slowing down
Traffic volume	Statements about the amount of traffic on the (upcoming) stretch of road	Much traffic / not much traffic
Adjust to traffic	Participant explains his/her driving reactions to other vehicles	I'm decelerating / accelerating to merge What is he doing? Anticipating lane changes of other vehicles I'm not going to overtake, but slow down I'm doing what they are doing Keeping distance
Overtaking	Statements about (the desire to) overtake	I want to go faster (the other one is going too slow) I'm going to overtake
Pre-sorting	Statements about (the desire to) pre-sort	I am going to switch lanes, to be prepared
Lane-keeping	Explicit mentions of not changing lanes	I stay in my lane (to anticipate upcoming events)
Speed related to curve		
Decelerating for curve	Statements about the action of decelerating in (front of) a curve	I'm slowing down for that curve Because of this curve, I'm slowing down
Accelerating after curve	Statements about the action of accelerating out of a curve	We have left the curve, now I'm accelerating Back to speed now
Curve-related		
Curve sighting	Clear statement about sighting and anticipating an upcoming curve	I see an upcoming curve I see other traffic going through a curve
Anticipating radius	Statements about the (upcoming) curve's radius (sharpness)	It is a sharp curve It is not such a sharp curve
Anticipating length	Statements about the (upcoming) curve's length or angle	It is a long turning curve It is a short curve
Curve direction	Statements about the (upcoming) curve's direction	A curve to the left / right
Curve end	Clear statement about sighting and anticipating the end of the present curve.	I can see the end of the curve
Oversight	Statements about being aware of the trajectory of the upcoming road section	I know where the curve is heading I have oversight
No oversight	Statements about being unaware of the trajectory of the upcoming road section	I don't know where the curve is heading, can't see through the curve I have no oversight I can't see what's happening
Speed sign	Explicitly mentioning the presence of a speed sign, either maximum speed or advice, or just the amount of km/h allowed	I notice a speed sign Oh, it's 50 here It is a maximum speed / it's just an advice I notice trees
Trees	Explicitly mentioning a treeline on the outside of a curve. Trees in the inside curve obstructing the view are labelled as no oversight	
Warning sign	Explicitly mentioning the presence of a curve warning sign	A sign tells me a curve is coming up
Curve sign (chevron)	Explicitly mentioning the presence of a curve chevron sign	I see curve signs
Other cues		
Type of road	Statements of the type of (upcoming) road (section) the participant is on	We're entering the freeway again This doesn't feel like a freeway I wouldn't expect this on a freeway
Number of lanes	Mentions of specific or relative number of lanes Also mentions of lanes based on route signing	Just one lane Too many, more, less lanes

(continued on next page)

(continued)

Label	Definition	Example verbalisations
Lane ending	Mentions of a lane ending	Oh, a lane drop is coming up
Special marking	Mentions of all types of special marking	You're not allowed to drive over those markings
Route signing	Mentions about the direction the participant (can) go	I'm looking where to go That's where I need to go (in xxx meters) Junction/off-ramp ahead
Overpass	Mentions of an overpass ahead	I notice an overpass
Pause		
Pause	A clear pause in a full sentence. The second part of the sentence is a clear follow-up of the first part	... uuuhm
Not related to external speed cues		
Non-speed-related	All other, non-speed-related verbalisations, such as distractions, other (traffic) signs, complex situations such as tapers, tiredness, general car	Hey, a nice building, car, train, traffic on other carriageways etc. Good car, stable on the road

Appendix B. Supplementary data

Supplementary data to this article can be found online at 4TU.ResearchData: <https://doi.org/10.4121/21069820>. This dataset includes:

- GPS data of the researched sections
- Filtered Eye-tracking data, containing the fixations, timestamps and AoI labels
- Verbalisations
- 6 muted video's of the HD-camera from the eye-tracker, containing fixation data (a video for each curve, from a single participant)
- Results from the questionnaires

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