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Research Article

How do dutch drivers perceive horizontal curves on freeway interchanges and which cues influence their speed choice?

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ABSTRACT

Operating speeds in Dutch freeway curves differ often by 20 km/h compared to their design speeds. Operating speed is thought to be influenced by how drivers perceive curves when approaching a curve. This explorative research explores which curve cues and other variables influence drivers' speed choice in curves. For this purpose, a survey was designed with 28 sets of curve comparisons. The curves were chosen from interchanges in the Netherlands and were compared to each other. To avoid direction bias, the curves were right turning only. In each set illustrations of two different curves out of a total of 8 curves were shown, and the participants were asked in which curve they would drive faster. In total 819 participants in the age range of 18 and 78 (mean= 41.3; Std.=11.9) completed the survey. The survey data showed four common categories of curve cues and variables influencing the decision to drive faster, of which those in the category of the road environment and its surroundings were mentioned the most. The top three variables influencing speed choice are visibility of curve characteristics, "overview" as a holistic but as such hard to measure variable, and number of lanes. Variables such as presence of signage and trees were also mentioned frequently by the respondents. Geometric road characteristics such as curve radius and deflection angle were identified by the respondents as influencing variables, but only showing to affect speed selection when these are visible to the driver and not obscured by trees or other elements. This suggests combinations of geometric and surrounding elements are needed to get a better understanding of speed selection by drivers.

1. Introduction

Design of freeway curves is usually based on design speeds [1–3] which use physical forces in point mass models [4] to tie speed and curve radius together. This results in design speeds that are a function of superelevation and radius, in order to reduce the risk of skidding and offer a comfortable ride. These design speeds are therefore mainly based on physical models of the forces between the infrastructure and the vehicle through skid resistance, and between infrastructure and the driver through comfort coefficients. There is, however, a difference between design speed and operating speed.

Measuring operating speeds and connecting these to geometric curve characteristics lead to speed prediction models [5–7]. These show significant correlations between curve radius, superelevation and operating speed, resembling the way design speed is modelled. Speed prediction models, however, also show that the operating speeds in Dutch curves are well above the design speeds [8], so curve geometrics such as radius and superelevation do not have a direct (causal) relationship with operating speed. A correlation however does exist, because with smaller radii lower speeds are selected, so in some way curve geometric characteristics are perceived by the drivers and used to select an operating speed. Differences in design speeds and operating speeds well over 20 km/h [8] could thus be explained, because driver characteristics and perception are usually overlooked in setting the design speeds. An understanding of how drivers select their operating speeds could lead to a design practice in which driver characteristics and perception are taken into account, and to a design based on human behaviour instead of physics alone.

The available literature on driver behaviour in curves generally remains rather conceptual though, but it gives some insights towards speed selection in curves. For example, driving task descriptions [9,10] give insights in the different zones of curve driving: curve not yet in sight (anticipation), curve in sight (discovery), within a curve (negotiation) and exiting a curve (leaving). These zones need different tasks, such as turning the steering wheel in curve negotiation. In terms of speed estimation by the driver, speed signs and curve radius are mentioned as primary indicators. The perception of the curve radius itself becomes better when getting closer to the curve, being at best at the

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start of the curve itself [11]. Transition curves however could distort the perception of curvature [12]. In curve negotiation the tangent point is the spot that gets the most attention of the driver [13–15]. The perception of curve cues is an automated process [16] of perceptual exploration and the memory drivers have of curve cues. The memory of different curves is stored in schema and help drivers to quickly select a speed based on cues they perceive [17–19]. This speed selection is a skill-based process [18] and does not involve active thinking while driving, because it is based on experience and memory. At the skill-level, errors could for example happen when drivers do not perform an attentional control over the intended action and therefore a wrong routine is activated [20]. This means that not enough attention is paid to the curve cues, or curve cues are misinterpreted and the wrong speed is selected [21].

These conceptual insights lack quantitative variables measuring their influence on speed choice. Such variables therefore cannot be incorporated in complex designs. To our best knowledge no research has been done on the cues that drivers use to choose their operating speeds in curves. The aim of this research is to explore which curve characteristics drivers use to select an operating speed to drive through curves. Because of the explorative nature of this research, a good method to start gaining insight into these variables is to ask the drivers themselves [22]. A survey is a useful method to ask a large sample of drivers for their reasons to select an operating speed through curves. Since the driving task is mainly visual [23,24], a well-known method is to show respondents photos and pictures as stimuli [19]. We further elaborate on this in the method section.

2. Method

This section first presents the main research questions, followed by the survey design, curve selection, survey respondents and analysis approach.

2.1. Research questions

The main question in this explorative study is: Which curve cues are used by Dutch drivers to select their operating speed through a curve? To answer the main question, two sub-questions were defined as follows:

(1) Which reasons (variables) for selecting their operating speed are identified by respondents?
(2) How are these reasons related to actual curve characteristics?

2.2. Survey design

The survey was designed in Dutch using Google Forms. First, information about the aim of the survey was given to respondents, followed by an informed consent which the respondents were asked to sign to give permission to use their anonymous data. The main part of the survey showed pictures of pairs of curves. Static pictures were used to prevent biases that could arise based on perceived speed (or deceleration) in videos. Videos have inherent cues based on locomotion [17]. A video incorporating vehicle speeds could be chosen by the respondents based on these dynamics, instead of its curve characteristics, which are the main aim of this research. To overcome this the same speeds could be used in the videos but that would result in very unrealistic videos. In addition, comparing pairs of videos is more difficult and time consuming for participants than comparing pictures. Therefore, we chose to use pictures instead.

Each presented picture included a pair of curves. Respondents were asked to compare them and pick the curve through which they think they would drive faster. Eight different curves were compared to each other, resulting in 28 different comparisons. The comparisons were shown in random order to overcome sequence bias. The goal of these comparisons was two-fold. First by comparing all 8 different curves to one another, it would be possible to rank the curves in terms of how often they were chosen. The second and main goal was to activate the thought process needed to answer the question which followed the 28 comparisons: “What are your reasons to drive faster in a curve?”. Speed selection in curves is probably a skill-based process [18] which does not involve active thinking while driving. By asking the main question after a dichotomous comparison task in which respondents were asked to choose between two curves, it was assumed that this has activated their thinking about speed selection. A dichotomous answer option was chosen over a Likert Scale because a dichotomous option forces the respondent to think about differences, without having the easy “neutral” option. This could give insights into particular schema or scripts being activated. Furthermore, by not providing pre-stated answer possibilities (as in [25]), it was hoped that this would lead to a variety of reasons mentioned. Finally, in the last part of the survey the participants were asked to optionally provide information regarding their gender, age and driven kilometres a week.

2.3. Curve selection

The curve selection was done based on three predetermined road geometric characteristics that were encountered in the literature on the perception of curve characteristics [11,26,27]: radius, deflection angle and number of lanes. All selected curves were right turning to prevent bias towards turning direction, because drivers behave differently in curves with different turning directions [28]. In addition, there is larger variation in the curve radius in right turning curves because they include curves with deflection angles between 50 and 300 degrees. The 8 selected curves are presented in Table 1 together with their geometric characteristics. ‘R_h’ is the horizontal radius measured in meters, this is thought to be the major cue in speed prediction [9,11]. ‘R_v’ is the vertical curvature in meters with a positive number being a sag curve and a negative number being a crest curve. It is measured because vertical alignment is thought to influence the perception of horizontal radius [29]. ‘i’ is the superelevation in %, which plays a major role in setting design speeds. ‘W’ is the road width measured in meters and number of lanes is an integer number. Both are included because they might play a different role in curve perception. In order to measure the visibility of the curve in the pictures two different sight distances were measured, using the point where the picture was taken from. ‘S_r’ is the sight on length of road visible in meters, this is the length of road which is visible from the standpoint of the driver, which can be obstructed by a vertical crest curve, or obstacles in the inner curve, such as guardrail. ‘S_t’ is the sight on the length of the visible trajectory of the road. The trajectory of the road is also visible through elements parallel to the road geometry, such as guardrail, trees, fences, earthworks, etc. These elements also contribute to the prediction of the path of the road [30]. This makes ‘S_t’ a broader concept than ‘S_r’. Fig. 1 illustrates an example of measuring ‘S_r’ and ‘S_t’ in curve A15. The sight on the road itself is obstructed by guardrail (the dashed-dotted line), so only the black part of the road is visible which is measured as ‘Sr’, the grey part of the road is invisible to the driver. The treeline in the outside curve gives the driver sight of the trajectory of the curve until the end of the curve because the trees are high enough to be visible over the entire length of the curve. The length of the treeline is measured as ‘St’. Since A15 does not have a vertical crest curve, this does not obstruct ‘Sr’ or ‘St’. In some cases, ‘S_r’ and ‘S_t’ are the same, because there are no extra trajectory cues available than the road itself. Not the entire deflection angle is visible in the pictures. Therefore the visible angle ‘$Ø_v$’ is taken into account, which is measured in gradians and represents the angle of the visible trajectory of the road (S_t) as shown in Fig. 1.

Curves A01, A02 and A59 were selected as a trio to compare the effect of the number of lanes present, while the radius remained similar. Curves A50 and A77 were selected as a duo in which the radius was different, but the number of lanes remained the same. Curves A15 and A28

Table 1
Geometric characteristics of the selected curves.

Curve ID	R_h (m)	R_v (m)	i (%)	W(m)	Number of lanes	S_r(m)	S_t (m)	$Ø_v$ (g)
A01	239	-57035	4.5	15.44	3	138	159	42
A02	249	∞	4.5	10.77	2	134	134	34
A09	180	-2551	7.0	11.77	2	80	275	97
A15	60	10419	3.0	8.70	1	63	192	204
A28	64	∞	7.0	8.08	1	103	103	102
A50	206	12939	4.5	8.57	1	183	183	57
A59	255	3416	7.0	7.80	1	122	263	66
A77	346	10171	5.0	7.21	1	140	226	42

were selected as a duo in which the visible angle changed while the radius and the number of lanes remained the same. Finally, curve A09 was selected as an extra curve to fill the gap in radii between 64 and 239 meters. Curve ID's were created based on freeway numbering in The Netherlands. The actual locations are hyperlinked in Table 1.

As introduced, it is the main goal of this explorative study to identify curve cues which drivers think are important when selecting their operating speed. Eight curves with unique characteristics do not provide enough data to perform meaningful statistical analyses on curve characteristics. The amount of 28 comparisons, however, were assumed to generate active thinking by the respondents to answer the main question. This is hoped to identify reasons for driving faster through a curve. At the same time, 28 comparisons are a fair amount for participants to complete in such a survey. At the start of the survey respondents were informed that it would take about 5 minutes to complete it.

The pictures were taken from CycloMedia [31], a database containing approximately 168 million pictures of 1 million kilometres of roads in the Netherlands. Pictures are updated frequently, so various conditions of each road are available. CycloMedia pictures show the viewing perspective in between that of a truck driver and a passenger car driver. Pictures with about the same weather conditions were selected and with as few other vehicles in the picture. Pictures were selected that were taken at the start of the curve itself, because that is where drivers can perceive the curve best [11]. The pictures also show the tangent point of the curve approximately in the middle of the picture, because the tangent point is the spot that is looked at the most by the driver [13–15], and therefore resembles the most natural viewing direction.

2.4. Survey respondents

The survey was spread throughout social media, such as LinkedIn, Facebook, Twitter, and mailing lists to colleagues, friends, family, alumni groups, etcetera. This resulted in 820 responses, of which 819 gave consent to use their input. All respondents were Dutch. In total 74% of the respondents were males (n=607) and 25% (n=206) were females, 1% (n=6) did not answer the question or did not want to disclose their gender. The age of the 689 respondents (not all respondents answered the age question) ranged from 18 (which was the set minimum) to maximum 78 (mean = 41.3; Std.=11.9). Frequencies of age and gender are shown in Fig. 3(A), while Fig. 3(B) shows the distribution of the amount of km the respondents drive per week.

Based on the people owning a driver's licence in the Netherlands [32], our sample shows an over-representation of the 30-40 age group, and an under representation of the 60 – 80 age group (Fig. 3A). Our sample also shows an over-representation of male drivers while the distribution of kilometres driven per week is on average similar [32]. Given the exploratory nature of this research and the fact that we had a relatively large sample of respondents (819), the slight over-representation of ages 30 – 40 and under representation of ages 60 - 80 does not pose a problem. The over-representation of males in the sample is discussed further in the Results and Discussion section.

2.5. Analysis Approach

The analysis approach consisted of three main steps. First, the reasons behind choosing to drive faster on one curve over the other, based on the open question, were investigated and then grouped in 21 different variables. The grouping was based on sets of words which had the same meaning and pointed in the same direction. For instance, the variable "visibility" is defined by words as looking, seeing, and visible. "Visibility" in that way is a variable which is measurable as a sight distance. The variable "overview" was created because the Dutch word "overzicht" was mentioned often by the respondents. It is a hard to measure variable, which has a more holistic and contextual connotation. By going through the responses, a list of synonyms was created, which was then used to categorise answers into one or more variables. A cluster analysis on respondents' answers was conducted to identify how variables would be clustered.

After the analysis of the variables mentioned by the respondents, it was counted how often each respondent chose a certain curve. In the comparison task eight curves were compared to each other. So, a

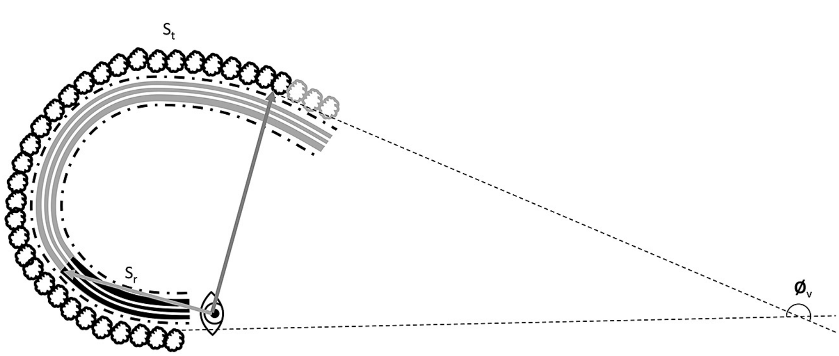

Fig. 1. An example of measuring sight distance on road 'S_r', sight distance on trajectory 'S_t' and visible angle '$Ø_v$' in curve A15, of which the picture is shown in Fig. 2

curve could be picked a maximum of seven times and a minimum of zero times. The amount of times a certain curve was selected leads to a ranking, and the curve which was picked most often, was assumed to be the curve which the respondent thought to drive through with the highest speed. This ranking was compared in a qualitative manner to the actual curve characteristics in order to gain insight in which curve characteristics relate to operating speed selection.

Finally, data from specific groups of respondents within the survey were further analysed. These groups do not constitute a representative sample of the population of Dutch drivers. However, each group is represented relatively well in this sample, and we look into the results of these specific groups to gain insight into the overall usefulness of the outcome of the first two steps.

3. Survey results and discussion

3.1. Reasons for driving faster

The open question in the survey gave much insight into the reasons why respondents would drive faster through a curve. These answers were grouped into 21 different variables and summarised into 4 different commonly identifiable categories as summarized in Table 2. The first category relates to the road environment and its surroundings. The second category concerns the road geometric characteristics of the curve itself. The third category are driver related factors, and the last category refers to external influences. Table 2 shows in detail the different identified variables and the number of respondents that mentioned these variables. Each respondent provided on average more than one reason, so the sum of n in the table is larger than the number of respondents (819).

The following sub-sections discuss the results in Table 2 per category.

Table 2
Reasons for driving faster.

Categories and variables	%	n
Road environment and surroundings	82%	668
• Visibility	71%	583
• Overview	34%	275
• Presence of signage	20%	162
• Presence of trees	9%	77
• Presence of guardrail	6%	48
• Presence of obstacles	5%	43
• Guidance	5%	39
• Marking	3%	22
Geometric road characteristics	57%	465
• Number of lanes	35%	284
• Radius	28%	229
• Road width	17%	136
• Road type	5%	38
• Vertical alignment	5%	38
• Deflection angle	4%	32
• Superelevation	3%	24
Driver related factors	21%	172
• Driving style*	9%	70
• Familiarity	3%	25
• Type of vehicle	1%	9
External influences	16%	130
• Pavement conditions	7%	60
• Traffic conditions	5%	41
• Weather conditions	3%	28

* This includes reasons regarding feelings, hurry, status, excitement, fun, safety, etc.

3.1.1. Road environment and surroundings

Elements of the general appearance of the curve were mentioned the most by the respondents. These include visibility and overview, but also the presence of signage, trees, guardrail, obstacles, markings and guidance in general. Having a good overview and being guided through the curve were generalised reasons having to do with most of the variables. This implies that drivers use the whole curve environment to select their operating speed. Visibility was mentioned in most of the answers. It includes words as looking, seeing, and visible. Visibility being the most mentioned variable confers the statement that 90% of the driving task is visual [23,24]. The answers focus on the need to see where the road is going, which resembles the visible angle '$Ø_v$'. A specific type of visibility is mentioned as 'overview'. In total 34% of the respondents gave a clear statement about the importance of overview in choosing their speed. This is a much broader concept than regularly used as different sight distances in geometric road design and which corresponds to trajectory planning and looking ahead [30]. It cannot easily be quantified through a measure in the field, because the answers given by respondents related to overview are not related to a single curve characteristic or set of characteristics.

One fifth of the respondents answered that when there are no curve signs they would drive faster. Since only 20% of the respondents mentioned curve signage, it is possible that the other 80% of the respondents did not notice the signage, perhaps due to some form of inattentional blindness [33,34] while performing the curve assessments. Another explanation could be that the other 80% just do not value the presence of signage.

When a respondent mentioned the presence of trees in their answers, they had different and conflicting reasons, either as giving guidance, or obstructing the visibility of the curve. A distinction between inner and outer curve was not made in the present study, but earlier simulator studies have shown that trees in the inside curve trigger drivers to reduce their operating speeds in curves [35,36]. Respondents usually mentioned the presence of guardrail as an obstacle and restricting the ability to look ahead, but also in reference to guidance. Guidance as a general term was mentioned by 5% of the respondents. It was usually mentioned as leading towards selecting a higher speed. Marking as a guiding principle did not seem to play a big role because marking in all the pictures was adequate, and there was not much variability among the curves.

3.1.2. Geometric road characteristics

Over half of the respondents mentioned reasons related to the geometric characteristics of the curve. This includes the number of lanes, the radius, the type of road, vertical alignment, angle and superelevation. When looking into these variables, the answers of the respondents show strong relation with visibility and overview. This implies that a single curve characteristic needs to be evaluated within the context of the entire curve surrounding. Respondents reason that when more lanes are available, their operating speed will be higher, but some respondents mention the opposite; they do not like other traffic besides them. Having the possibility to overtake makes it more attractive to drivers to travel with higher speeds. It also corresponds to the relation between more lanes and larger radii mentioned in older Dutch design guidelines [37]. These guidelines were used to design many curves which are still present in today's freeway system in The Netherlands, and therefore in the memory of many drivers. This points towards drivers' expectations regarding the relation between more lanes and bigger radii. Results of simulator studies [26,38] also show this, as well as speed observations made on Dutch freeway curves [39]. Respondents state that if the road width itself increases, so does their operating speed. A total of 35 respondents mentioned both road width and number of lanes, making it a minority in the group of respondents mentioning road width. It is therefore unclear whether road width is perceived and interpreted in the same way as number of lanes. Curve radius itself is quite a technical term, so mentions of sharpness, curviness, etcetera have been included under this variable as well. This is supported by earlier research on perception of curves [11] which identified these types of words to correspond to radius. Respondents usually mentioned that when a curve has a larger radius, they would select a higher speed. Different types of road (main carriageway, connector road, etc.) and discontinuities (exits, freeway junction, fork, etc.) were mentioned by very few respondents to influence their speed choice, perhaps because the pictures did not explicitly show this type of road sections. Road type seems to refer to the concept of self-explaining roads [40] and drivers' ability to construct expectations on upcoming elements (such as sharp curves) based on the general road layout. Respondents answered they would drive faster on a main carriageway compared to connector roads. Vertical alignment refers to all mentions of hilliness, grades, going up, acclivity, etc. Respondents reasoned that crest curves obstruct overview but up-going slopes gave them a better overview of the situation. There is also evidence that drivers (in simulators) chose different speeds when confronted with crest or sag curves, based on a distortion of their perception of the horizontal curvature [29]. Deflection angle is a variable used to capture all the mentions of angle, long curves and degrees. Deflection angles have earlier been shown to be of significant importance [11] to curve perception. Superelevation is hard to see in a picture, probably therefore only a few of the respondents mentioned it as a reason. So, here we see a difference between curve perception and curve design. Superelevation is a variable of major importance in curve design but seems to play a minor role in curve perception.

3.1.3. Driver related factors

Much fewer respondents gave insights into reasons that relate to their own driving style or other personal motivations. We use the term driving style as a generalisation of reasons regarding feelings, hurry, status, excitement, fun, safety, etc. Different driving styles (positive and negative) were included in this variable and recent research which focussed more on driving style showed differences between moderate and aggressive drivers [41]. This type of differentiation could not be made based on the answers given in this survey, because only 9% of the respondents gave answers in this direction without mentioning it being negative or positive. Some of the respondents mentioned they would go faster through a curve when they are familiar with the curve and know what is coming. Naturalistic driving studies have also shown a relation between familiarity and higher speeds [42]. The type of vehicle the respondents drive was mentioned by only 1% of the respondents. An Australian study [43] showed that drivers of different types of vehicles have different schema of the same situation. A memory schema helps the driver optimize their behaviour based on expectations stored in memory. These schema help drivers select a speed based on cues they perceptually receive [17–19].

3.1.4. External influences

External influences are variables that lie outside the spatial design and the driver. The reasons mentioned by the respondents related to pavement, traffic, and weather conditions. Pavement conditions include maintenance, quality or the colour of the asphalt. Newer asphalt appeared more reliable to drivers and give them confidence in driving faster. Traffic conditions related to other traffic which could limit drivers' speeds or following behaviours. Some respondents also mentioned that they do not want to slow down other traffic. And finally, respondents mentioned that bad weather conditions would lower their operating speeds.

3.2. Cluster analysis

The 819 respondents used different combinations of variables in their answers. The count of those variables was given in Table 2. This table summarised the variables into commonly used categories, and not how these variables were combined in answers. Hierarchical clustering of the combined variables in respondent answers was conducted using 'ClustOfVar' package in R [44] which generated the dendrogram in Fig. 4.

The dendrogram in Fig. 4 shows seven identifiable clusters of variables (height above 1.0) used in the answers of the respondents. The clustering of radius, familiarity and road type suggests that drivers know what the radius is going to be, based on previous experiences. The presence of guardrail, trees and guidance might suggest that both trees and guardrail are thought of as either guiding elements in a curve, or that these obstruct guidance. Marking, road width and pavement conditions all have relations to the carriageway itself and this cluster might indicate how the road looks to drivers. The type of vehicle, driving style, and external weather and traffic conditions are closely related to each other in respondents' answers, and indicates that how drivers respond to external circumstances varies with both driver and vehicle characteristics. Visibility and overview are clustered, which appears logical because the term overview ("overzicht" in Dutch) is treated as a linguistically derived variable of visibility ("zicht" in Dutch) in this analysis. The clustering of deflection angle, superelevation and vertical alignment could hint at how well a curve is recognisable, since it is closely related to the visibility cluster. The cluster which groups the number of lanes with presence of signage is less obvious to explain, but could be interpreted as how clear the sharpness of the curve is 'readable' from cues other than guidance or the radius itself.

3.3. Curve Ranking

Based on the number of times respondents picked a curve throughout all the comparisons a ranking of the curves was made. Table 3 shows the overall ranking based on the average number of times respondents picked a curve to be the one they would drive through fastest. Table 3 also shows curve characteristics in order to compare these to the curve ranking.

The ranking in Table 3 is based on respondents' overall comparisons on which curves they think they would have driven faster, based on the pictures of the curves. Whether this would also represent actual operating speeds is still to be investigated. Speed prediction models suggest that higher operating speeds are to be expected in curves with larger radius [5–7]. However, the curve with the largest radius (A77) in Table 3 was not picked the most by the respondents. If we look at the curve surroundings in Fig. 2, we see that this probably has to do with the close surroundings of trees and therefore lack of perceived overview. The number of lanes could also contribute to this, since A77 only has one lane, which does not lead the respondents to expect higher operating speeds. The curve which was picked most (A02) has two lanes and a wide overview, since no trees are present. Both cues are mentioned to be of influence for choosing higher speeds. A further look at Table 3 shows that curves with more than one lane are in the top 4 curve picks, while curves with larger radii but only one lane were picked less often by the respondents.

When looking at sight distances themselves ('S_r' and S_t'), they do not show a similar order as compared to the average pick. When sight distances are combined with the angle, some relation exist in the picking order and *visible* angle ('$Ø_v$'). Based on the results of this survey, the more curve angle is visible (i.e. '$Ø_v$' is larger), the less often a curve gets picked as being a fast curve. This makes sense, because the further we can see does not tell anything about what we see. So, combining curve surroundings as a measure of how far we can see the trajectory of the curve with a geometric curve element (such as the deflection angle) gives a more holistic approach. Visible angle ('$Ø_v$') however still does not explain fully how speed is selected and may not be generalizable to other curves based on this research alone. This needs to be explored with a bigger sample size and statistically tested. A more probable explanation for the relation between curve characteristics and ranking is that more curves without curve signs are picked as fast curves. This is logical because curve signs are placed at small radii.

The results show that the average pick is not ranked in relation to the available superelevation (%), which is in line with

Table 3
Curve ranking and curve characteristics.

Rank (most often picked to drive fastest)	Avg. pick	Std.	Curve ID	Rh (m)	i (%)	Number of lanes	S_r (m)	S_t (m)	$Ø_v$ (g)	Signage
1	6.06	1.23	A02	249	4.5	2	134	134	34	No
2	5.40	1.48	A01	239	4.5	3	138	159	42	No
3	3.99	1.44	A59	255	7	1	122	263	66	No
4	3.78	1.65	A09	180	7	2	80	275	97	Yes
5	3.56	1.62	A77	346	5	1	140	226	42	No
6	2.65	1.34	A50	206	4.5	1	183	183	57	Yes
7	1.26	1.16	A28	64	7	1	103	103	102	Yes
8	1.26	1.50	A15	60	3	1	63	192	204	Yes

Fig. 2. Overview of curve pictures shown in the survey taken from CycloMedia Technology B.V. Curve ID's were created based on freeway numbering in The Netherlands.

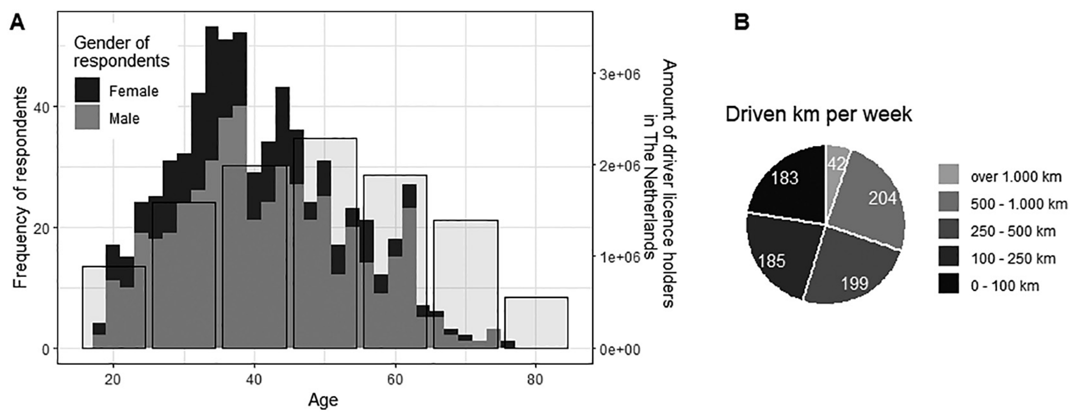

Fig. 3. (A) – Bar chart showing the distribution of ages of the respondents per gender, in light grey boxes the distribution of driver licence holders in The Netherlands is shown per age group in 2014 [32]; (B) – Pie chart showing the distribution of driven kilometres per week by the respondents

the small amount of times this variable was mentioned by the respondents.

Since only eight curves were compared, we decided not to quantify correlations or do some form of dimension reduction or regression analysis.

What Table 3 tells mainly is that ranking of curves based on pictures is more elaborate than looking at geometric curve design characteristics alone. Other characteristics mentioned by the respondents provide more insight in the way an entire curve is perceived. These characteristics often refer to holistic variables such as overview and guidance. Quantification of such a holistic approach, or even an approach based on Gestalt principles [45] is however very difficult to attain, because there are so many variables to be taken into account.

3.4. Specific groups within the survey

Within the respondents three groups were looked further into: experts, younger and female respondents.

The survey was spread through the personal network of the first author (road design expert and researcher), which could have led to bias in the outcomes. To check this, we searched for the use of professional and technical terms that are usually not used by lay persons in the reasons given by respondents to drive faster through curves. This led to 14% to 27% of the respondents being identified as experts, depending on which terms were used as a filter. The results showed that experts only picked curve A77 significantly more often than lay persons (χ^2 (7, n=819) = 17.73, p=0.013), the other curves showed no significant difference. This suggests that curve A77 was selected more often by the participants in the present study as compared to the entire population.

Driving experience is important in how well one can estimate how fast the driver can travel through a curve [16–19]. This would suggest that younger respondents (age 18-23, n=36) would differ in their survey answers from older respondents (age 24-78, n=783). However, no variable was mentioned significantly more or less often by the younger respondents compared to the older ones.

Since female respondents (n=206) are under-represented in the sample, we investigated whether they assessed the curves in this study differently than male respondents (n=607). The female respondents mentioned radius significantly more often (χ^2 (1, n=813) = 4.46 , p=0.035); they never mentioned superelevation; they mentioned vertical alignment significantly less often (χ^2 (1, n=813) = 6.08 , p= 0.014) and also mentioned guidance and overview less (χ^2 (1, n=

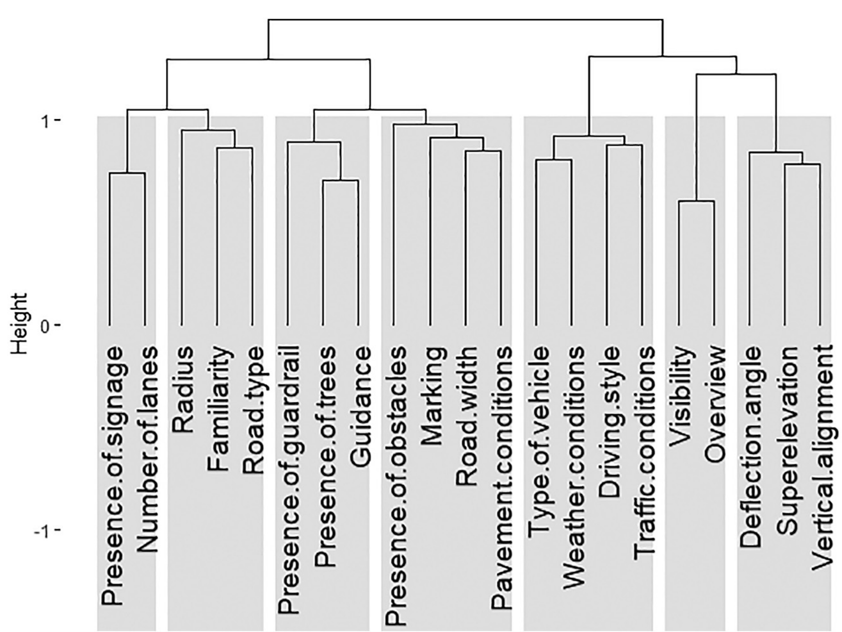

Fig. 4. Cluster dendrogram of the variables used in the answers of the respondents.

813) = 8.14 , p=0.004, χ^2 (1, n=813) = 4.99 , p=0.025, respectively). This might indicate these characteristics play a less important role for the entire population than the findings of the present study suggest.

4. Conclusion

The results of the survey provide some insights in driver expectations about freeway curves which can readily be applied in curve design. Insights which may be used in design are for example, the reasons mentioned by the respondents to select an operating speed in a curve indicate that overview is needed to pick up references to the trajectory of the curve, such as tree lines, guardrail or anything parallel to the curve itself. The visibility of the trajectory could be a combination of the often mentioned variables visibility, overview and radius. Visible angle could therefore be a pragmatic dimension reduction which combines both behavioural and geometric aspects in terms of perception and deflection angle. Visible angle might have influenced the picking of curves for which higher operating speeds could be selected. In a follow-up study, this could be studied with a larger curve sample and observations of actual operating speeds.

Respondents indicated that their operating speed could be higher when more lanes are present. This corresponds to the design principles in The Netherlands [37] which link an increasing number of lanes to increasing radii. This means most multi-lane curves in The Netherlands have relatively large radii, so experience in driving through such curves could form expectations that in multi-lane curves higher speeds are possible. If this is indeed a generalised expectation of drivers, road designers should be careful designing small radii curves with multiple lanes because faulty routine activation by drivers could lead to errors [21] and accidents. Superelevation is of importance to design speed, and design guidelines mention that superelevation helps to detect an upcoming curve better. Based on this study however, superelevation does not seem to play a role in curve perception.

This study provides some first insights into possible directions for further research. Based on the results of this study, it is recommended that future research into predicting operation speeds in curves also incorporates variables that are identified as relevant for drivers for selecting their operating speed. Most of these variables are easy to measure, such as radius and number of lanes, others are easy to spot, such as the presence of trees and signs. Curve surroundings are not usually a variable in speed prediction models [5], but based on this study, there is good reason to include these. It is however difficult to quantify the most mentioned variable “visibility” since sight distances alone do not seem to have a clear relationship with speed. But visible angle ‘$Ø_V$’ might prove a valuable measure which combines sight distances with radius and deflection angle. Also, the term overview was mentioned by a third of the respondents. This seems to be a holistic concept, which is hard to quantify and use in a speed prediction model. Future research should include more curve characteristics and surrounding elements in an attempt to operationalise the variable “overview” in a speed prediction model.

This research is explorative in its nature and the survey itself is basic in its design, showing only pictures of eight different right turning curves. It is difficult to gain insights in drivers speed choice based on static pictures alone [17]. The ranking differed in that of the measured speed, so further research should focus on cues based on locomotion as well, but also use a larger sample of curves and explore other research methodologies beside static pictures. Since the setting of the survey and the respondents were Dutch, results might not generalisable to drivers in other countries who may have other expectancies about curves and speed selection.

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Declaration of Competing Interest

None.

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