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The effect of widening longitudinal road markings on driving speed perception

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A R T I C L E I N F O

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A B S T R A C T

Road markings may influence driver behavior, and therefore road safety. An increase in the width of road markings might lead drivers to perceive lanes to be narrower than they really are, creating the illusion of traveling faster. The objective of this paper is to analyze whether wider longitudinal road markings can affect the perception of lane width and thus induce drivers to slow down. To this end, three curves with reduced visibility were selected for a field experiment. The road markings were painted wider than normal, and video recordings were made with narrow and wide markings by a camera installed in a vehicle. A total of 14 videos were shown to each of the 185 participants; then a survey was carried out to analyze in which video the participants perceived higher speed. The results showed that if the participants perceived differences in speed, the higher speed was perceived with the wide markings. This perception of higher speed increased if the participant was female, or if the participant had ever had an accident. In view of the obtained results, it can be said that the use of wider road markings could help reduce vehicle speed, thus contributing to improved road safety.

1. Introduction

Traffic accidents cause around 1.35 million deaths worldwide per year (World Health Organization, 2018). Accidents are multifactorial, related to road, traffic, the environment, and human behavior, e.g. inappropriate speed, tiredness, or distraction while driving (European Transport Safety Council, 2017). Approximately 25% of fatal accidents occur on horizontal curves (National Academies of Sciences, 2004). Numerous researchers consider that speed should be underlined as a main factor contributing to the occurrence of road accidents (Zhang et al., 2014; Yu et al., 2015; Elvik et al., 2019), and to their severity (Elvik et al., 2019). According to the European Commission (2020), a speed increase of 10 km per hour (kph) doubles the risk of fatal accidents, while a reduction of the average speed by 1 kph on all roads in the European Union would save over 2000 lives per year. In this context, road markings are the most effective road safety treatment, given their cost-benefit ratio (COST, 1999).

Many studies have explored the influence of different longitudinal and transverse road marking treatments on road safety and on driver behavior. Although they may arrive at mixed or inconclusive results, the prevailing opinion is that road markings have a positive impact on road safety (Babić et al., 2020). Regarding the effect of wider longitudinal road markings on driving speed, previous studies are not conclusive either: most report that speed decreases (Lundkvist et al., 1990; SEOPAN and AEC, 2017; Retting et al., 2000; Calvo et al., 2020), whereas others do not find a clear effect on speed reduction (Daniels et al., 2010).

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The objective of the present paper is to analyze whether wider longitudinal markings can affect the perception of lane width and thus induce drivers to slow down.

The paper is organized into the following sections: literature review, methodology, data description, results, discussion, and finally, conclusions.

2. Literature review

There are numerous field and laboratory studies researching the influence of road markings on road safety, in terms of reducing traffic accidents, and on driver behavior, measuring parameters such as speed. In laboratory studies, generally using driving simulators, it is common to analyze driver behavior and the perception of different road marking treatments.

2.1. Studies analyzing the effects of road markings on road safety

Carlson (2015) conducted a *meta*-analysis focused on the effect of wider longitudinal road markings on accident reduction, obtaining no conclusive results. He found that the greatest benefit coming from wider markings was better peripheral visibility, which is related to major driving tasks, such as keeping within the lane. Cottrell (1987) evaluated the effect of wider markings on two-lane rural roads in Virginia, concluding that wider edge lines did not lead to a significant reduction in accidents. On the contrary, a reduction in traffic accidents (2% to 10%) was obtained after implementing wider longitudinal markings (8-inch, instead of the 4-inch standard used by Transport Agencies) in three road sections in the United States. According to these experiments, wider road markings meant a safety improvement helping to reduce accidents (American Traffic Safety Services Association, 2008). Carlson and Wagner (2012) reviewed the literature about accident reductions from installing wider edge lines, offering evidence as to wider road markings being beneficial for road safety. Thus, they recommend that agencies should use 6-inch edge lines instead of 4-inch on rural two-lane highways. Park et al. (2012) evaluated the safety effects of wider edge lines analyzing accident frequency data for road segments from three US states. Their study provided detailed evidence suggesting that wider edge lines were effective in reducing accidents on two-lane rural highways. Similarly, Hussein et al. (2020) obtained an overall significant reduction in traffic collisions of 12.3% after implementing the wider markings. They affirm that wider road markings have a positive effect on road safety by helping visibility and enhancing the lateral position of vehicles.

In summary, despite the fact that more studies indicate that wider longitudinal road markings contribute to reducing traffic accidents, to date there are no conclusive results about this key question.

2.2. Studies analyzing the effects of road markings on driving speed

To shed light on the relationship between experimental road markings and driving speed, Retting et al. (2000) analyzed in a field experiment the effects of longitudinal markings that narrowed the lane leading into a curve, by gradually narrowing the existing edge markings inward. Results showed this to be effective in reducing speed.

Daniels et al. (2010) analyzed the effect of a white 0.5 m long line painted close to the existing continuous edge line in the longitudinal direction and repeated every 50 m. The effect was evaluated both in field and on a driving simulator. The field's results did not show a significant impact of additional road markings on the driving speed. The simulator's results showed an impact on the lateral position of the vehicle, but did not show any impact on driving speed, in accordance with the field's results. The authors suggested that the stimulus of the markings was present, but it was possibly too weak to change the perception of the traffic environment and subsequently to change speed behavior. Carlson et al. (2013) evaluated the impacts of pavement marking width on observed driver speed and on crashes. Their study considered only wider edge lines (i.e., they did not analyze wider centerlines). The authors concluded that the wider edge lines had no significant impact on vehicle speed. However, they suggested that the use of 6-inch (15 cm) edge lines could reduce several types of crashes on two-lane two-way rural roads as compared to 4-inch (10 cm) edge lines. The authors indicated that additional research was needed to better understand how the use of wider edge lines could have a safety impact. The authors wonder what would be the result of increasing both the edge line and centerline width and whether the impact on two-lane rural highways would be even greater if 8-inch (20 cm) edge lines were used.

In another field study, Calvo et al. (2020) measured driving speeds with normal (narrow) and then with modified (wider) longitudinal road markings in three curves having reduced visibility. The results showed a slight speed reduction, of around 3.1%, with wider road markings. The authors concluded that wider road markings have a speed-reducing effect, which may be related to drivers perceiving the lanes to be narrower than they actually are.

Other researchers analyzed the effect of painting symbols, words, rumble strips or transverse lines on roads. Most report a reduction in speed with these treatments (Maroney and Dewar, 1988; Retting and Farmer, 1998; Godley, 1999; Godley et al., 2004; Lewis and Charlon, 2006; Katz, 2007; Montella et al., 2011; Hallmark et al., 2012; Ding et al., 2016; Liu et al., 2016; Hussain et al., 2021), although others (e.g., Agent and Creasy, 1986; Chrysler and Schrock, 2005; Charlton, 2007) do not obtain clear evidence of this effect.

In a field research, Agent and Creasy (1986) analyzed the impact of pavement delineations (raised road markers, transverse sriptes and rumble strips) and shoulder delineation (post delineators and chevron signs) on driver behavior. The results showed that both treatments did not significantly decrease speed except chevrons, but encroachment decreased substantially, and the number of accidents decreased in three of the four locations where road delineation was implemented.

Maroney and Dewar (1988) painted transverse lines on a road at progressively decreasing distances, observing that the number of drivers who exceeded the recommended speed by more than 30 kph was reduced by 25 percent. However, this treatment had no long-term effect on speeding because it began to disappear after three weeks. In a similar study, Katz (2007) used peripheral transverse lines spaced at a frequency of four bars per second, which reduced vehicle speeds by up to 59% in the short term and 24% in the long term. This experiment was also carried out using a driving simulator. However, in the case of the simulator no decisive conclusions could be made.

Regarding other types of experimental markings, Retting and Farmer (1998) painted the word “slow” on the pavement of a left curve and a left curve arrow above it. Speed data were collected before and after painting the pavement markings, and results indicated a decrease of 7% in average speed. Hallmark et al. (2012) measured the driving speed in two curves, determining higher speeds at the beginning and lower speeds in the center of one curve, but lower speeds for any location in the other one.

Chrysler and Schrock (2005) studied the efficacy of painting the words “curve ahead” on the pavement, finding no speed changes. Another treatment included “curve 55 mph” pavement markings, which helped to reduce speed by 4 miles per hour (mph), although the difference was not statistically significant.

Further studies have relied on driving simulators to analyze the effect of road markings on speed. For example, Godley (1999) examined the speed reduction effectiveness of different road marking treatments that included a chequered edgeline wider (85 cm), which effectively produced lane narrowing illusions. He concluded that the width of the edgeline may affect driver speed and hence lead to slower traveling speeds. Godley et al. (2004) used wide center markings to produce a road narrowing effect and lead drivers to reduce their traveling speed. Lewis and Charlon (2006) studied the adaptation of the speed behavior of drivers in response to a manipulation of the road width on three two-lane rural highways. The results showed narrow roads to be associated with lower speeds. Charlton (2007) tested road markings curve treatments using a driving simulator. The study concluded that only rumble strips significantly reduced the speed. The use of double yellow centerlines had no apparent effect on drivers’ speeds. Although it was envisaged that the herringbones pavement marking would narrow the effective lane width and reduce drivers’ speeds, contrary to

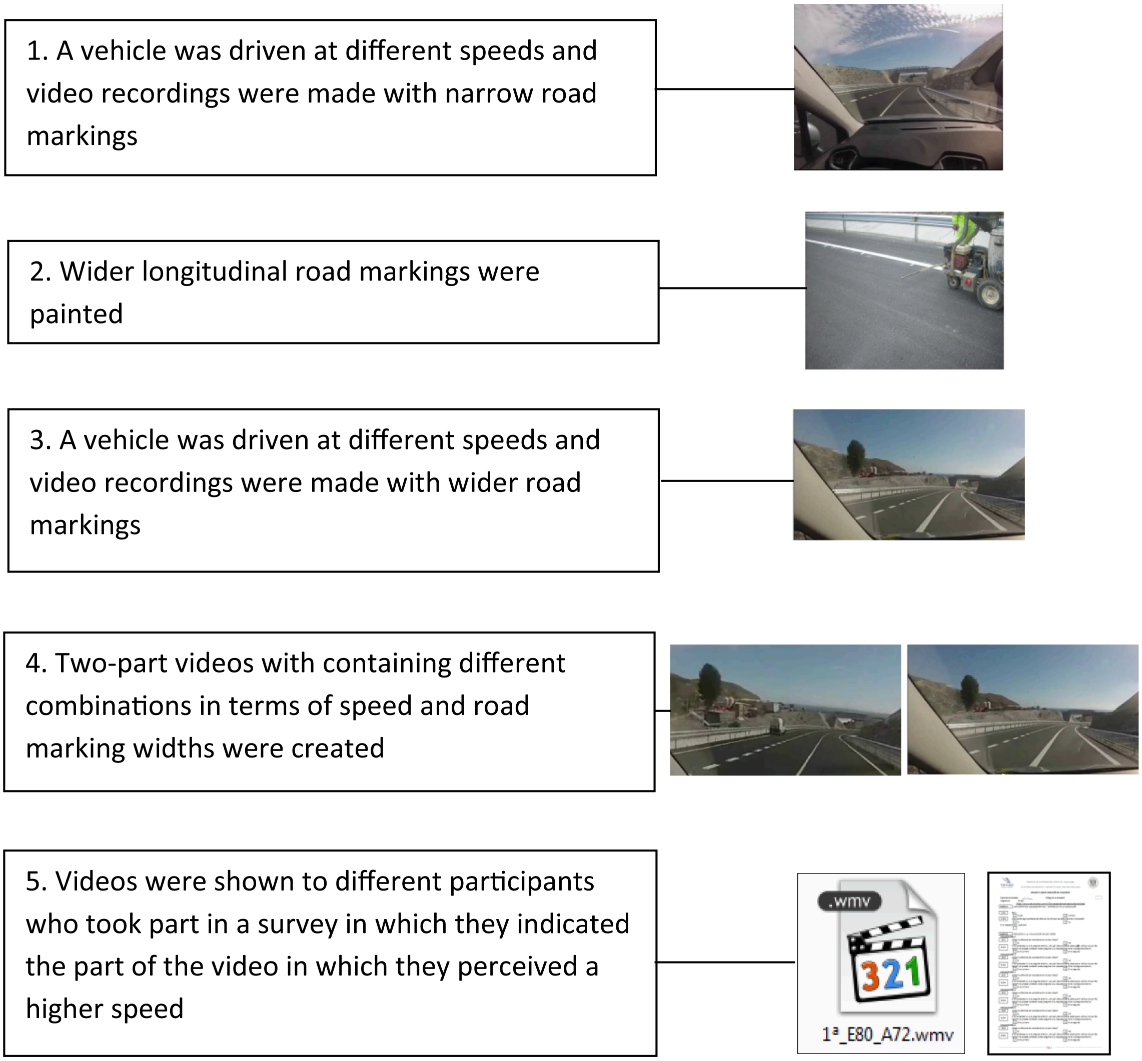

Fig. 1. Methodology diagram.

expectations these pavement markings did not produce any appreciable reductions in drivers' speeds.

Montella et al. (2011) analyzed the behavior and speed of drivers approaching intersections in relation to different signals. Two of the most effective road marking treatments were the so-called dragon teeth markings, based on the principle of optical road narrowing; and the raised median island, based on the principle of physical road narrowing. Both measures produced a significant reduction in speed.

Liu et al. (2016) analyzed driver speed in an underground urban expressway where lane and shoulder widths varied. They affirm that narrowing lanes serves as a means to slow down drivers because a narrow lane may increase the level of perceived risk.

Ding et al. (2016) explored the effects of Longitudinal Speed Reduction Markings on multi-spoke urban interchange connectors in a driving simulator. They found that this kind of treatment could reduce vehicles' traveling speed.

Hussain et al. (2021) showed that speed limit pavement markings with a gradual increase in brightness and/or size produced an impression of speeding up that could stimulate drivers to slow down to better adapt to speed limits. In terms of size, the results indicated that the average speed reduction was not significantly different between the genders; yet average speed reductions were significantly higher for women when compared to men in the presence of glossy pavement markings and mixed concepts.

Therefore, in light of the corpus of literature, even though most authors studying the effect of wider road markings on road safety and on speed consider that wider road markings generally have a positive effect on increasing road safety and decreasing speed, previous studies have not yet provided conclusive results. As for other types of treatments —i.e. based on painting symbols on the pavement— there appears to be more consensus, but still, some authors find no clear evidence of these treatments helping to reduce driving speed. At any rate, one may accept that, in general, these new types of road markings can be considered an effective road safety treatment in the sense that they produce a conscious or unconscious change in driver behavior that may affect driving speed, and thus road safety.

According to the above, there are not many studies that have analyzed the effect of increasing the width of longitudinal road markings on vehicles speed and driver perception. So, this study tries to contribute to the state of the knowledge on this subject in two ways: 1) using a different methodology that has not been previously used for analyzing the perception about driving speed based on field videos and surveys; and 2) comparing the perception of wide and narrow road longitudinal markings both at the center and edge lines.

The objective of this paper is, therefore, to determine the influence of wider longitudinal road markings in along horizontal curves on perceived driving speed. The hypothesis to be validated would be: Drivers tend to perceive a higher speed than the real one due to the narrowing of a lane caused by wider longitudinal road markings.

3. Methodology

3.1. Design of the investigation

Three curves were analyzed in this research. Fig. 1 shows the methodology followed to develop the study, organized in five phases:

In the *first phase*, field video recordings were made while driving along the curves. For this purpose, a camera was installed inside the vehicle at the driver's eye level, hence showing the driver's perspective. These initial recordings were made when the road markings had a normal width, in accordance with the current regulations (MOPU, 1987). From now on, this normal width will be called "narrow width". In Spain, the usual widths are 10 cm for lane separation and edge lines (15 cm for edge lines if the shoulder is greater than 1.5 m). Several passes were made along each curve at different constant speeds (from 68 to 100 kph), a video being recorded for each speed. The car's navigator was programmed before each recording to circulate at constant speed. In addition, the recordings were made in free-flow conditions —that is, the videos were only recorded when there were no cars in front of the car carrying the camera, so that other cars would not interfere with the speed of the vehicle making the recordings. Because the European Transport Safety Counciĺs overview of national studies on speeding in Europe (ETSC, 2014) showed that approximately 30% of drivers exceed the speed limit on motorways, and that over 70% drive too fast outside built-up areas, some of the video recordings in our study were made at speeds higher than the speed limit, to see whether the measure is effective for drivers traveling at high speeds, implying greater risk than slow driving.

In the *second phase*, the longitudinal road markings of the curves were painted with a greater width: the road marking of the lane separation was changed from 10 cm to 30 cm, and the road marking of the edge line was increased from 15 cm to 30 cm. Henceforth, road markings with a greater width will be referred to as "wide markings". A width of 30 cm was chosen, since the Spanish regulation recommends that the width should increase to 30 cm in some sections entailing a heightened possibility of conflict or risk to circulation: e.g. climbing lanes, merge and diverge segments, or specialized lanes such as bus lanes. The road markings contemplated under Spaińs regulations are discontinuous, whereas in this investigation continuous road markings are considered.

In the *third phase*, new field video recordings were made while the driver went along each of the curves, now with wide markings, several times at the constant speeds indicated in the first phase.

Then, in the *fourth phase*, the videos were edited by putting together different combinations of speed and road marking widths. Each video consisted of two parts, both of them showing the same curve; but the width of the road markings was different in each part: If in the first part of the video the road markings were narrow, then in the second one they were wide, and vice versa.

In the final phase, the videos were shown to different participants who answered a survey containing general data (e.g. gender and accidents suffered) and two specific questions: (1) Do you notice any difference in speed between the two videos? and (2) *If you answered YES to the previous question, in which video do you consider that the vehicle circulated faster?*. When the participant answered NO to the first question, this second question did not apply.

3.2. Curve selection

The first part of the research consisted of identifying dangerous curves, mainly as a result of their reduced visibility.

Two of the curves belong to a branch connection of the A-7 Motril-Carchuna road in Granada, Spain. The cross-section of the road consists of three lanes, two upward lanes and one downward lane (where the curves are located). The width of each lane is 3.5 m and the shoulders have a width of 1.5 m. The first curve (Curve 1) is a left curve and has a radius of 320 m and a gradient of −6.65%. The second (Curve 2) is a right curve with a radius of 270 m and a gradient of −8.0%. The maximum speed allowed on this road is 60 kph.

The third curve (Curve 3) is located on a two-lane road, the A-333 Alcaudete-Archidona road in Cordoba, Spain. The width of the lane is 3.5 and the shoulders have a width of 1.0 m. It is a right curve and it has a radius of 230 m, the gradient being −2.0%. The maximum speed allowed on this road is 90 kph, but just before the curve there is a recommendation of 70 kph. The three analyzed curves (Fig. 2) are preceded by tangents long enough so that they do not condition the driving speed in the curves.

3.3. Driving recordings and surveys

The recordings were made while driving at different constant speeds (from 68 to 100 kph) along each curve, with both narrow and wide longitudinal road markings.

Then, videos were created by combining different driving speeds for each curve, and using the wide (W) or narrow (N) road marking recordings in the first part of the video, and the opposite in the second one. Fourteen videos were finally shown to the

(a) Curve 1 on the A-7 road. Narrow markings

(b) Curve 1 on the A-7 road. Wide markings

(c) Curve 2 on the A-7 road. Narrow markings

(d) Curve 2 on the A-7 road. Wide markings

(e) Curve 3 on the A-333 road. Narrow markings

(f) Curve 3 on the A-333 road. Wide markings

Fig. 2. Analyzed curves.

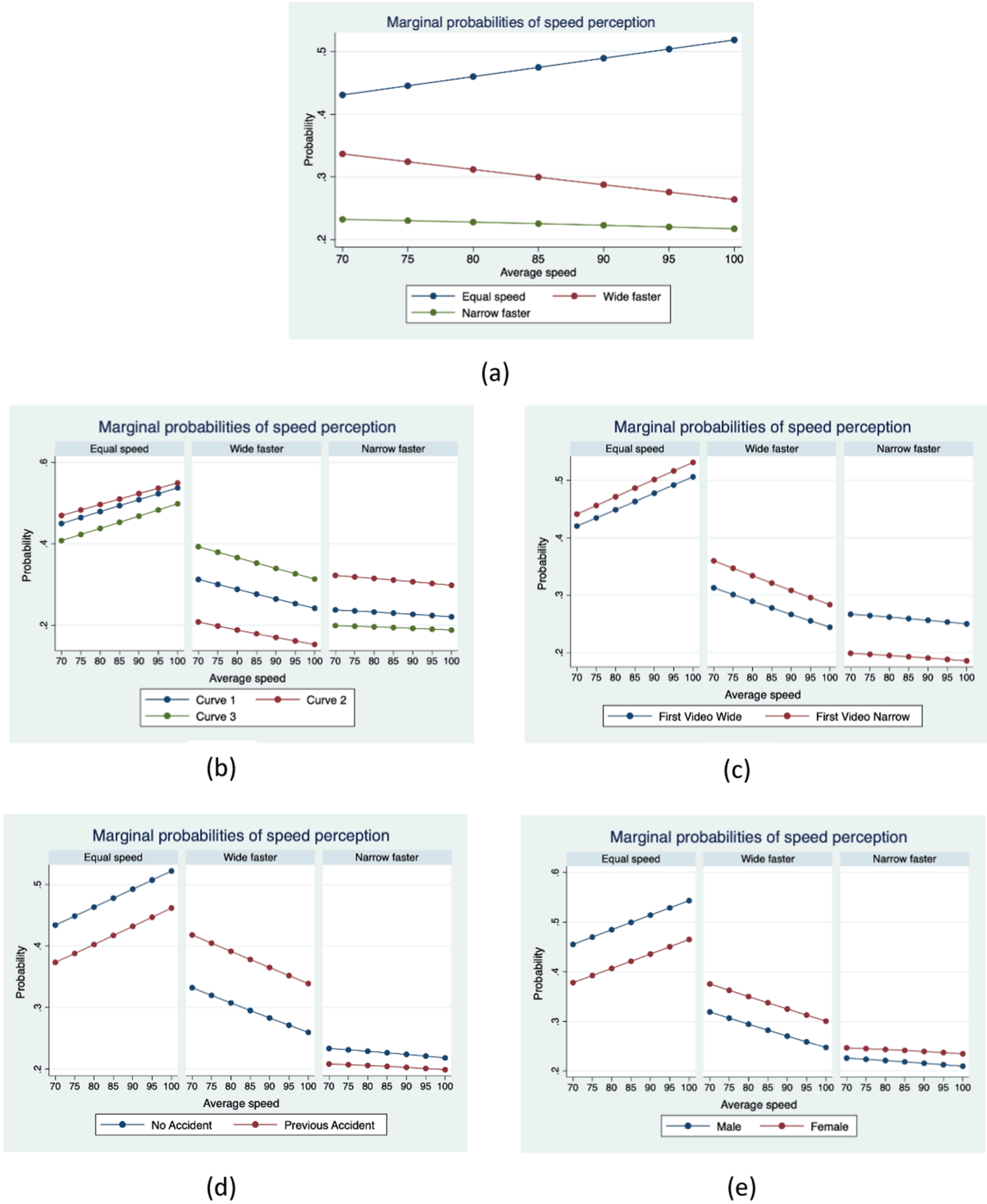

Fig. 3. Marginal probabilities of speed perception with average driving speed.

participants (Table 1). Recording speeds were chosen taking into account the maximum and the recommended speeds allowed on each curve as well as the driving safety during the videos' recording.

Initially, in the research design, speed differences of 5 km/h were considered, so that this variable could be appreciated. The recordings were made with rented vehicles, therefore we did not have control over the car assigned to us at any given time. The recordings in Curves 1 and 2 were made with a vehicle that allowed to fit the speed at intervals of 2 kph. In this case, videos with speed differences of 4 km/h were recorded (as a value close to the initially planned). The recordings in Curve 3 were made with a different

Table 1
Videos shown to participants.

Video	Curve	First Video	Second Video
		Width Speed	Width Speed
1	Curve 3	W80	N80
2	Curve 1	N76	W80
3	Curve 3	W70	N75
4	Curve 2	N80	W80
5	Curve 3	N100	W100
6	Curve 1	N68	W68
7	Curve 3	N80	W75
8	Curve 2	W72	N76
9	Curve 3	W80	N75
10	Curve 1	N80	W72
11	Curve 3	W90	N90
12	Curve 2	N68	W68
13	Curve 3	N90	W95
14	Curve 1	W80	N80

*W: Wide; N: Narrow.

vehicle that allowed speed intervals of 1 km/h so, videos with speed differences of 5 km/h were recorded.

The number of videos for the survey was set at 14 to limit the duration of the survey, also considering that in each video two parts had to be viewed. Among the 14 videos, 50% have the same speed associated with the wide and narrow marks (four videos in C1 and C2 and three videos in C3) and the other 50% have different speeds (three videos in C1 and C2 and four videos in C3).

The interpretation of Table 1 is as follows (See Table 1, row 2): Video 2, part 1: the recording shows circulation at 76 kph along C1 with narrow road markings (N76), and driving along C1 at 80 kph with wide markings (W80). The videos were shown in the order indicated in Table 1 (it will be called “normal order”) to half of the participants and in the reverse order to the other half. For example, video 2 (See Table 1, row 2) was shown to half of the participants as N76 W80 and to the other half as W80 N76. The goal of changing the order was to see whether the narrow markings or the wide markings being shown first in the video had any influence on the participants’ responses.

After that, the participants were asked whether they perceived speed differences between the two parts of the video. If the answer was affirmative, the participants had to indicate in which part of the video they perceived a higher speed. The answer to these questions is the dependent variable of the statistical model used to analyze the data.

3.4. Statistical analysis

For the research, each participant had to choose between three different options: not perceiving any difference in speed between the two parts of the video; perceiving a faster speed in the video in which the road markings are wide; perceiving a faster speed in the video in which the road markings are narrow. Considering that each participant had to choose between three alternatives, and given the type of the response variable, a multinomial logit model (MNL) was chosen. The MNL are popular methods for modeling categorical outcome variables where the categories do not have a natural order. The MNL was developed for data in which respondents can choose only one option from a set of discrete alternatives (McFadden, 1974).

In panel data, a sequence of outcomes for the same individual is observed. As 14 videos were shown to each person, and different choices were made by the same individual, the data has a panel data structure. Moreover, the choices that individuals make are not independent because they may depend on preferences or individual characteristics. These characteristics generally remain unobserved in the data. The random effect estimators of MNL help to explain this unobserved heterogeneity, because the model includes an additional error term at the panel level. It is known as the heterogeneity term, and is shown in the model in addition to the error term; it represents the heterogeneity in the different videos observed by the same individual.

Therefore, the aim is to examine the choice from different options using panel data through the choice that provides the greatest utility. The utility perceived by the *ith* participant faced with J choices supposes that the utility of choice j is (StataCorp., 2021):

$$U_{ijv} = x_{iv}\beta_j + u_{ij} + \varepsilon_{ijv} \tag{1}$$

where U_{ijv} is the utility of the ith individual toward outcome j in video v, with $i = 1,\ldots,N$, $J = 1,\ldots,J$, and $v = 1,\ldots,14$. The part observed is $x_{iv}\beta_j$, with x_{iv} as a row vector of covariates that varies across the individuals, and βj is a column vector of coefficients for outcome j. The unobserved part is made up of the following error components: The panel-level heterogeneity term, uij, and an observation-level error term. εijv.

Let y_{iv} be a random variable that indicates the choice made with video v. Then, when the data consist of choice individual specific characteristics, the natural model formulation is:

$$\Pr\left(y_{iv} = m | x_{iv}, \beta_j, u_{ij}\right) = \frac{\exp(x_{iv}\beta m + u_{im})}{\sum_{j=1}^{J}\exp\left(x_{iv}\beta j + u_{ij}\right)} \tag{2}$$

The above equation is normalized with respect to a base category. In order to do so, both the elements of βj and uij are set to zero for one of the categories of the result variable. If the base outcome is assumed to be 1, the probability that the ith individual chooses the result m at time t is:

$$\Pr\left(y_{iv} = m | x_{iv}, \beta_j, u_{ij}\right) = F\left(y_{iv} = m, x_{iv}\beta_j + u_{ij}\right) = \frac{1}{1 + \sum_{j=2}^{J} \exp\left(x_{iv}\beta_j + u_{ij}\right)} \; if m = 1 \tag{3}$$

$$\Pr\left(y_{iv} = m | x_{iv}, \beta_j, u_{ij}\right) = F\left(y_{iv} = m, x_{iv}\beta_j + u_{ij}\right) = \frac{\exp\left(x_{iv}\beta_m + u_{im}\right)}{1 + \sum_{j=2}^{J} \exp\left(x_{iv}\beta_j + u_{ij}\right)} \; if m > 1 \tag{4}$$

Here, F(.) is defined as the cumulative logistic distribution function.

The predicted probabilities provide clear graphical information about the direction and magnitude of the relationship. However, it may prove difficult to determine precisely whether a relationship can really be established, especially in places where the curve is flat. To solve this, the marginal effects must be calculated. Marginal effects are defined as the slope of the prediction function at a given value of the explanatory variable. Therefore, they report the change in predicted probabilities due to a change in a particular predictor (Wulff, 2015). The random effects estimator is described in Hartzel et al. (2001). In this paper, marginal effects will help to interpret the results.

As can be seen in Table 1, there are seven videos (1, 4, 5, 6, 11, 12, 14) in which the driving speed was the same in both parts of the video; three videos (2, 9, 13) driving at a higher speed with the wide markings; and four videos (3, 7, 8, 10) in which the speed is higher with the narrow markings. Therefore, in most of the videos the driving speed was the same in both parts (seven videos, versus three and four with different speeds). These differences can lead to an over or under representation of a certain case in the model. In order to avoid this bias, calibration involved adjusting the number of observations using a weighting strategy. This approach aims to ensure that all cases are equally represented in the model.

The variables used in the random effects multinomial logit model are described in Table 2.

The dependent variable, called “perceived speed”, indicates if the participant perceived a speed difference between the two parts of the video or not (1), if the participant perceived a higher speed in the part of the video with wide road markings (2), or if he/she perceived a higher speed in the part of the video where the road markings were narrow (3).

Moreover, the following were considered as independent variables:

- Average Speed: Continuous variable indicating the average of the circulating speeds of the two parts of the video.
- Speed Difference: Continuous variable indicating the difference in speed between the two parts of the video.
- Female: Binary variable (1: Female, 0: Male).
- Previous Accidents: Binary variable that indicates whether the participant has ever had an accident (1: Yes, 0: No).
- First Video: Narrow: Binary variable indicating if the road marking was narrow in the first part of the video, thus being wide in the second part (1: Yes, 0: No).
- Curve: Binary variable indicating if the curve shown is Curve 1 (1), Curve 2 (2), or Curve 3 (3).

4. Data

As the 14 videos (Table 1) were shown to 185 participants, the analysis stemmed from a database with 2,590 cases. Data were carefully proofed to eliminate anything that might be erroneous, so that the final number of participants was just 173 and the number of cases 2,413. Most erroneous records were due to inconsistencies between questions (1) and (2) as indicated in the last paragraph of Section 3.1.

This group of participants comprised 54 women and 119 men. Only nine people had suffered an accident, meaning any associations

Table 2
Variables used in the conditional model.

Variable	Coding	Description
Dependent		
Perceived Speed	Equal speed: 1; Wide faster: 2; Narrow faster: 3	The participant did not perceive a difference in speed (1). The participant perceived a higher speed when the road marking was wide (2). The participant perceived more speed with the narrow marking (2)
Independent		
Average Speed (kph)	0, 68,72.5, 74, 76, 77.5, 78, 80, 90,92.5, 100	Average Driving Speed. It is the average of the speeds of the two videos shown
Speed Difference (kph)	−5, −4, 0, 5, 8	Driving Speed Difference. It is the difference of the speeds of the two videos shown (Speed in video with wide markings minus speed in video with narrow markings)
Female	0: Male; 1: Female	Gender of the participant
Previous Accidents	0: No; 1: Yes	It indicates whether the participant has ever had an accident
First Video Narrow	0: No; 1: Yes	It is (1) if the road marking was narrow in the first part of the video and it was wide in the second part. Otherwise, it is (0)
Curve	1: Curve 1; 2: Curve 2; 3: Curve 3	It indicates the curve shown. It is (1) for Curve 1, it is (2) for Curve 2, and it is (3) for Curve 3

Table 3
Participant response to speed perception.

Video/ Order	Curve	1st Part Width Speed	2nd Part Width Speed	Do not appreciate a difference in speed	Appreciate a higher speed when road marking is wide	Appreciate a higher speed when road marking is narrow
1/Normal	Curve 3	W80	N80	54	26	12
1/Reverse	Curve 3	N80	W80	51	22	8
2/Normal	Curve 1	N76	W80	30	56	6
2/Reverse	Curve 1	W80	N76	41	22	17
3/Normal	Curve 3	W70	N75	41	13	38
3/Reverse	Curve 3	N75	W70	53	13	14
4/Normal	Curve 2	N80	W80	50	27	15
4/Reverse	Curve 2	W80	N80	42	19	19
5/Normal	Curve 3	N100	W100	44	37	11
5/Reverse	Curve 3	W100	N100	40	21	20
6/Normal	Curve 1	N68	W68	54	18	19
6/Reverse	Curve 1	W68	N68	33	24	24
7/Normal	Curve 3	N80	W75	28	10	54
7/Reverse	Curve 3	W75	N80	36	9	35
8/Normal	Curve 2	W72	N76	31	17	44
8/Reverse	Curve 2	N76	W72	27	15	39
9/Normal	Curve 3	W80	N75	19	66	7
9/Reverse	Curve 3	N75	W80	24	52	4
10/Normal	Curve 1	N80	W72	48	13	31
10/Reverse	Curve 1	W72	N80	28	10	42
11/Normal	Curve 3	W90	N90	57	11	24
11/Reverse	Curve 3	N90	W90	56	15	10
12/Normal	Curve 2	N68	W68	63	10	19
12/Reverse	Curve 2	W68	N68	53	16	11
13/Normal	Curve 3	N90	W95	34	54	4
13/Reverse	Curve 3	W95	N90	42	32	7
14/Normal	Curve 1	W80	N80	49	27	15
14/Reverse	Curve 1	N80	W80	50	23	8
			Total	**1,178**	**678**	**557**

*Half of the participants were shown the videos in one order (named normal order) and the other half of the participants were shown them in reverse order. For example, video 1 was shown to half of the participants as W80 N80 and to the other half as N80 W80.

concerning this variable should be viewed with caution. Age was not relevant, since the study was carried out only among university students (between 20 and 23 years old, approximately).

5. Results

Table 3 displays the participantś responses to each video:

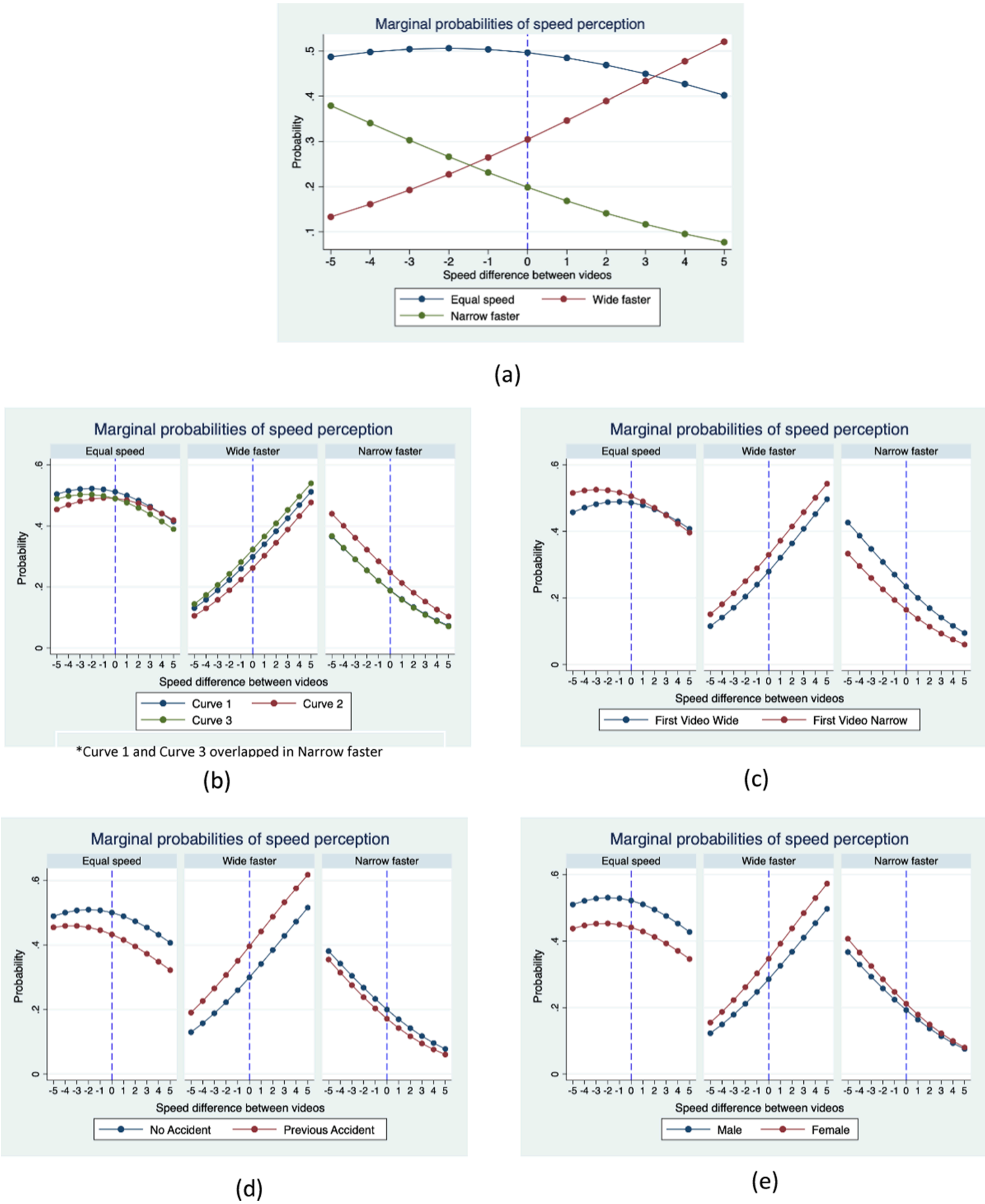

Fig. 4. Marginal probabilities of speed perception with speed difference.

As seen in Table 3, nearly half the participants detected no difference in speed (1,178 out of 2,413 cases), 678 perceived a higher speed when road markings were wider, and 557 noted a higher speed with narrow markings.

Focusing on the participants who reported a difference in speed (see last two columns of Table 3), three cases can be highlighted:

- Cases in which the speed is the same in both parts of the video (511 cases): In 296 cases, a higher speed is perceived with the wide markings, and in 215 a higher speed is perceived with the narrow markings.
- Cases in which the speed is higher with the wide markings (338 cases): In 215 cases a higher speed is perceived with wide markings, and in 123 a higher speed is perceived with narrow markings.
- Cases in which the speed is higher with narrow markings (386 cases): In 167 cases a higher speed is perceived with wide markings, and in 219 a higher speed is perceived with narrow markings.

Based on the information above, it seems clear that: (1) if the speed is the same in both parts of the video, 57.9 percent of the participants perceive higher speed when the markings are wide (this difference can be seen in terms of probability in Fig. 4a); and (2) if the speeds are different, most participants perceive this difference, and choose correctly, that is, they select the video where the driver goes faster, regardless of whether the marking is wide or narrow. These results reflect the influence of wide markings in inducing drivers to perceive a higher speed than the real one.

Table 4 presents estimated coefficients, p-values, variances, and covariances. Stata MP 16.1 software was used. In addition, the estimated coefficients were transformed to odds ratios or relative risk ratios (that is, eβ rather than β). However, the odds ratios still do not provide a very intuitive way to interpret the results. Predicted probabilities can likewise be calculated to evaluate the relationship between a predictor and each outcome; margins use predicted probabilities that account for random effects. Plotting the predicted probabilities provides a quick and informative way to present the relationship between a selected predictor and the predicted probabilities of the different alternatives. Fig. 3 shows margin graphs of the average driving speed in function of the dependent variable in order to facilitate the interpretation of results. In turn, Fig. 4 offers margin graphs for the speed difference with respect to the rest of the variables. While these graphs could have been repeated for all the variables, their inclusion would have made the paper repetitive; the most relevant results show up in the speed variables (average driving speed and speed differences between videos).

In Table 4, the base category would be the participant not perceiving any speed difference between the two parts of the video. At the bottom of Table 4, the estimated variances of the random effects, corresponding to the nonbase equations, are shown. A considerable variance is seen in the panel-level unobservables. The lower bound of the 95% confidence interval is not close to zero, relative to their estimated standard errors. Covariances are significant, as they indicate that random effects are correlated.

The results of Table 4, Fig. 3, and Fig. 4 point to the following:

- For a good look at the odds ratios, the upper part of Table 4 (see last column) shows the results of comparing the probability of a participant perceiving a higher speed when the markings are wide, as opposed to the base category, that is, compared to the participant perceiving the same speed in both parts of the video. This probability increases with the following variables: Speed difference between the two parts of the video (it is 1.22 times more likely, this variable being significant); In Curve 3, located in a two-lane road, when compared to Curve 1, located in a three-lane road (it is 1.35 times more likely); If the first marking shown is

Table 4
Model parameters and goodness-of-fit indicator.

	Coef.	Robust Std. Err.	z	p>|z|	[95% Conf. Interval]		Odds ratios
Wide faster: 2							
AvgSpeed	−0.019562	0.008828	−2.22	0.027	−0.036864	−0.00226	0.980628
DiffSpeed	0.199446	0.020961	9.52	0.000	0.158363	0.240529	1.220726
Curve							
2	−0.149945	0.180386	−0.83	0.406	−0.503494	0.203605	0.860756
3	0.300680	0.182860	1.64	0.100	−0.057720	0.65908	1.350777
FirstMarkNarrow	0.167060	0.12427	1.34	0.179	−0.076504	0.410625	1.181826
Accidents	0.538631	0.722274	0.75	0.456	−0.877000	1.954262	1.713659
Female	0.460953	0.250563	1.84	0.066	−0.030141	0.952046	1.585584
Cons	0.500624	0.703472	0.71	0.477	−0.878156	1.879403	1.649750
Equal: 1 (Bases alternative)							
Narrow faster: 3							
AvgSpeed	−0.009791	0.009228	−1.0	0.289	−0.027879	0.008296	0.990256
DiffSpeed	−0.160271	0.019891	−8.06	0.000	−0.199257	−0.12128	0.851913
Curve							
2	0.339696	0.167848	2.02	0.043	0.010721	0.668671	1.404520
3	0.106889	0.164992	0.65	0.517	−0.216490	0.430268	1.112811
FirstMarkNarrow	−0.457213	0.121361	−3.77	0.000	−0.695076	−0.21935	0.633046
Accidents	0.008317	0.480621	0.02	0.986	−0.933683	0.950318	1.008352
Female	0.327861	0.198313	1.65	0.098	−0.060826	0.716547	1.387995
Cons	−0.328528	0.746097	−0.44	0.660	−1.790851	1.133795	0.719983
var(M1[id])	1.764054	0.444783			1.076199	2.891552	
var(M2[id])	1.360428	0.331691			0.843608	2.193867	
cov (M1[id], M2[id])	0.692104	0.199117	3.48	0.001	0.301841	1.082366	

the narrow marking (it is 1.1818 times more likely); If the participant has ever suffered an accident (it is 1.71 times more likely); and if the participant is female (it is 1.59 times more likely).

- This probability decreases with the following variables: The average speed of the videos shown (it is 0.98 less likely, this variable being significant), and in Curve 2 when compared to Curve 1 (it is 0.86 times less likely).
- Fig. 3a illustrates how the probability of perceiving no difference in driving speed between the two parts of the video is higher than the probability of perceiving some difference, and it increases with speed. One remarkable result is that the probability of perceiving a higher speed when the markings are wide is greater than the probability of perceiving a higher speed when the markings are narrow; yet this probability decreases with speed.
- In general, the probability of perceiving a higher speed when the marking is wide is greater than this probability when the marking is narrow, though it decreases as the average speed increases (Fig. 3a). This effect is more notworthy for Curve 3 (Fig. 3b) if the first video shows narrow markings (Fig. 3c), if the participant has ever had an accident (Fig. 3d), or if the participant is female (Fig. 3e).
- Regardless of the speed difference between videos, the probability of perceiving no difference in speed is higher than the probability of perceiving a difference in speed, except when the difference is over 3 kph (Fig. 4a).
- When there is no speed difference between the videos, the tendency to perceive a higher speed with wide markings is superior to the one linked to perceiving narrow markings (Fig. 4a). This effect is somewhat stronger when the first markings shown in the video are the narrow ones (Fig. 4c); when the person has undergone a former accident (Fig. 4d); or when the participant is a woman (Fig. 4e).
- When the speed difference is over -1.5 kph, the probability of perceiving a higher speed with wide markings is greater than the probability of perceiving a higher speed with narrow markings (Fig. 4a). Yet it should be stressed that the perception of a higher speed with wide markings also occurs when the circulation speed is greater with narrow markings (up to 1.5 kph higher), which gives us as researchers some idea of the effect of wide markings.
- The bottom part of Table 4 displays the results of comparing a) the probability that an individual perceives a higher speed when the markings are narrow, versus b) the base category, that is, not perceiving any speed difference. This probability increases with the following variables: in Curves 2 or 3, versus Curve 1 (it is 1.41 times more likely in Curve 2, and 1.11 times more likely in Curve 3); if the participant has ever had an accident (1.01 times more likely); and if the participant is female (1.39 times more likely). This probability decreases in conjunction with the following variables: difference in speed between the two parts of the video (0.85 times less likely); average speed (0.99 times less likely), or if the narrow markings appear in the first part of the video (0.63 times less likely) —results that can likewise be observed in Fig. 3 (see the graphics “narrow faster”).

In general terms, the results summarized in Table 4 and Figs. 3 and 4 indicate that the probability of a participant perceiving a higher speed in the part of the video in which the road markings are wide is greater than the probability of perceiving a higher speed when the road markings are narrow. This points to the narrowing effect of wide markings that heighten onés perception of a higher driving speed.

6. Discussion

These results are consistent with previous findings in the literature that also suggest that certain road marking treatments could produce changes in driver behavior that might affect driving speed (Godley, 1999; Godley et al. 2004; Lewis and Charlon, 2006; Calvo et al., 2020; Retting et al., 2000). However, we have to acknowledge there are also some studies that do not identify significant changes in speed behavior (e.g., Charlton, 2007; Daniels et al., 2010; Carlson et al., 2013).

Higher speeds are perceived when the lane width seems narrower, making drivers go somewhat more slowly. As for experimental road markings, when Retting et al. (2000) reduced the lane by moving the edge markings inward in their field study, it proved effective in reducing speeds. Similarly, our research focusing on the participants who reported a difference in speed, shows that when the markings are wide, the participants perceived that the driver went faster, probably owing to the fact that the lane appeared narrower; in response, they reduced velocity. Furthermore, this effect is more accented when the speed is the same with wide markings and narrow markings.

Calvo et al. (2020), finding that actual vehicle speeds decreased with wide markings on curves, suggested it could be due to the use of wide markings. Godley (1999) concluded that a wider edgeline may lead to slower travel speeds. Drivers reduced their velocity when Godley et al. (2004) used wide center marks to produce a narrowing effect on the road. In turn, Lewis and Charlon (2006), who likewise studied driving speed linked to a varied width of the highway, demonstrated that on narrower highways speed tended to be lesser.

Our research would indicate that, as the mean speed of circulation increases, the effect of the wide markings decreases. Even though no previous studies come to support such findings, it might be surmised that such measures could be more effective on roadway stretches that are governed by lower average speed limits (dangerous zones, tight curves…).

According to the results put forth here, females are more likely ($p < 0.10$) to perceive a higher speed when road markings are wide than when road markings are narrow. The influence of gender has been analyzed in previous studies (Charlon, 2007; European Commission, 2020; Hussain et al., 2021). Indeed, even the European Commission (2020) states that the perception of speed may vary according to gender, men generally driving faster than women. The study by Hussain et al. (2021) showed that the average speed reduction was not significantly different between genders, with regard to the size of road markings. However, when variations in the brightness of the markings were included, and when such variations were combined with differing sizes of the road markings, the average speed reductions recorded were significantly higher for females as opposed to males. These authors therefore demonstrated that bright pavement markings and road markings that combined changes in their brightness and their size bore a greater impact on females than males. Charlon (2007) did not arrive at any significant differences owing to gender, age, or a recent history of accidents when they tested several types of road markings to analyze effects on the driver speed.

Finally, our results suggest that, for Curve 3, the probability that a driver/participant would perceive higher speed when the markings are wide is greater than for the other two curves studied here. It must be said that Curve 3 pertains to a two-lane road section, while the other curves have three lanes. This suggests that increasing the width of longitudinal road markings might be more effective when the total roadway width is lesser. Shorter radii and a narrower shoulder in C3 may also have influenced this particular finding. Previous research involved diverse road types: Lewis and Charlon (2006) or Calvo et al. (2020) carried out their studies on two-lane rural roads. Retting et al. (2000) developed their study on urban freeway exit ramps with horizontal curves. The setting of Liu et al. (2016) was underground urban expressway, and that of Ding et al. (2016) involved multi-spoke urban interchange connectors. While these studies cannot compare results owing to the different roadway types, in all of them the findings resembled ours in one aspect: A driver reduces the vehicle speed when the lane either is or else appears to be narrower, most likely because this factor entails or induces a perception of higher velocity. In our case, the participants perceived greater speed when the lane seemed to be narrower, possibly sparking a reduction in their driving speed.

Regarding the effectiveness of the measure over time, in Curve 3, real speeds were measured using radars (Calvo et al. 2020). These measures were taken during 157 days with narrow markings, and during 289 days with wide markings. It was observed that wide markings contributed to decreasing speed during the whole period. Therefore, the measure is expected to have a long-term effect, although it has not been verified over the years.

7. Conclusions

This study stems from an experiment consisting of painting longitudinal road markings that were wider than the norm under Spanish regulations, at the edge and center of lanes. The wider road markings narrow the lane, at least apparently, which seems to influence drivers in the sense that they perceive they are driving faster than they are actually doing. As the most remarkable results, deserving mention are:

- If the speed is the same in both parts of the video, most of the participants perceived a higher speed when the markings were wide. Moreover, when the speed was higher with wide markings, the percentage of individuals who perceived more speed with this type of marking proved higher than the proportion of individuals perceiving a higher speed with narrow markings when the higher speed was with narrow markings. These two results illustrate how wide markings may induce drivers to perceive a higher speed than the real one.
- The probability that a participant perceives a higher speed when the markings are wide (versus not perceiving any speed difference) increases with the speed difference between the two parts of the video involved in our study, as well as in Curve 3, having the smallest radius of the three curves studied here.
- The probability of appreciating a higher speed when the marking is wide is higher than the probability when the marking is narrow, and this probability decreases as the average speed increases. Moreover, this likelihood is higher for Curve 3 if the participant has ever had an accident, or if the participant is female.
- Almost half of the participants in the survey perceived a higher speed with wide markings if the speed difference is over −1.5 kph, which implies that the perception of a higher speed with wide markings occurs even when the circulation speed is greater with narrow markings (up to 1.5 kph higher).

Granted, this study has some limitations, being carried out only with university students, and very few participants had had a previous accident. Extrapolating the conclusions to a broader age range would require another survey. Despite this limitation, it may be affirmed that wide road markings can affect driver behavior by narrowing the lane, that is, onés perception of the lane. This narrowing effect can lead drivers who are going faster to reduce their driving speed, meaning fewer road accidentes along dangerous sections like curves. Thus, the study hypothesis has been validated. Regarding practical applications of the study results, given the vast number of accidents occurring on curves, many of which are due to speeding, specific measures implemented in the wake of such studies could help road administration agencies to improve road safety. The measure has only been applied in curves, but the application in other dangerous areas such as intersections is proposed as a future line of research with the aim of analyzing whether speed reductions and therefore fewer road safety conflicts could be obtained.

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.

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References

Agent, K., Creasy, T., 1986. Delineation of horizontal curves, Report, p. 47, Kentucky Transportation Research Program, Lexington, USA.

American Traffic Safety Services Association, 2008. Low cost local road safety solutions. Available at: https://www.michigan.gov/documents/mdot/Low_Cost_Local_Road_447132_7.pdf.

Babić, D., Fiolić, M., Babić, D., & Gates, T. (2020). Road Markings and Their Impact on Driver Behaviour and Road Safety: A Systematic Review of Current Findings. *J. Adv. Transport., 7843743*.

Calvo-Poyo, F., de Oña, J., Morcillo, L. G., & Navarro-Moreno, J. (2020). Influence of wider longitudinal road markings on vehicle speeds in two-lane rural highways. *Sustain. (Switzerland), 12(20), 1–11*, 8305.

Carlson, P., Wagner, J., 2012. An Evaluation of the Effectiveness of Wider Edge Line Pavement Markings.

Carlson, P. J., E. S. Park, A. M. Pike, R. J. Porter, J. Miles, B. Boulanger, O. Smadi, N. Hawkins, S. Chalmers, F. Darmiento, A. Burde, B. Kuhn, and W. Ealding., 2013. Pavement Marking Demonstration Projects: State of Alaska and State of Tennessee. FHWA-HRT-12-048, Federal Highway Administration, Washington, D.C.

Carlson, P.J., 2015. Synthesis of Pavement Marking Research. (Report FHWA-SA-15-063). Federal Highway Administration, Washington, DC.

Charlton, S. G. (2007). The role of attention in horizontal curves: A comparison of advance warning, delineation, and road marking treatments. *Accid. Anal. Prev., 39* (5), 873–885.

Chrysler, S.T., Schrock, S.D., 2005. Field Evaluation and Driver Comprehension Studies of Horizontal Signing. FHWA/TX-05/0-4471-2. Texas Transportation Institute.

COST (1999). Requirements for horizontal Road marking. Final report of COST 331 action. Brussels: European Commission.

Cottrell, B. H. (1987). Evaluation of Wide Edge Lines on Two-Lane Rural Roads. *Transp. Res. Rec., 1160*, 35–44.

Daniels, S., Vanrie, J., Dreesen, A., & Brijs, T. (2010). Additional road markings as an indication of speed limits: Results of a field experiment and a driving simulator study. *Accid. Anal. Prev., 42*(3), 953–960.

Ding, H., Zhao, X., Ma, J., & Rong, J. (2016). Evaluation Research of the Effects of Longitudinal Speed Reduction Markings on Driving Behavior: A Driving Simulator Study. *Int. J. Environ. Res. Public Health, 13*(11), 1170.

Elvik, R., Vadeby, A., Hels, T., & van Schagen, I. (2019). Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. *Accid. Anal. Prev., 123*, 114–122.

European Transport Safety Council (ETSC), 2014. PIN Flash 16. Tackling the three main killers on the roads. A priority for the forthcoming EU Road Safety Action Program. Brussels.

European Transport Safety Council (ETSC), 2017. Reducing Deaths in Single Vehicle collisions. Available at: https://etsc.eu/reducing-deaths-in-single-vehicle-collisions-pin-flash-32/.

European Commission, 2020. Road safety thematic report–Speeding. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport.

Godley, S., Fildes, B., Triggs, T., Brown, L., 1999. Perceptual countermeasures: experimental research. Road Safety Research Report CR 182. Australian Transport Safety Bureau, Canberra, Australia.

Godley, S. T., Triggs, T. J., & Fildes, B. N. (2004). Perceptual lane width, wide perceptual road centre markings and driving speeds. *Ergonomics, 47*(3), 237–256.

Hallmark, S.L., Hawkins, N., Smadi, O., 2012. Evaluation of Low-Cost Treatments on Rural Two-Lane Roads. Report No. IHRB Project TR-579. Midwest Transportation Consortium and Iowa Department of Transportation, Ames, IA, July.

Hartzel, J., Agresti, A., & Caffo, B. S. (2001). Multinomial logit random effects models. *Statist. Model., 1*, 81–102. https://doi.org/10.1177/1471082X0100100201

Hussain, Q., Alhajyaseen, W. K. M., Reinolsmann, N., Brijs, K., Pirdavani, A., Wets, G., & Brijs, T. (2021). Optical pavement treatments and their impact on speed and lateral position at transition zones: A driving simulator study. *Accid. Anal. Prev., 150*, Article 105916.

Hussein, M., Sayed, T., El-Basyouny, K., & de Leur, P. (2020). Investigating safety effects of wider longitudinal pavement markings. *Accid. Anal. Prev., 142*, Article 105527.

Katz, B. J. (2007). *Peripheral Transverse Pavement Markings for Speed Control, PhD. Dissertation*. Blacksburg, Virginia: Virginia Polytechnic Institute and State University.

Lewis-Evans, B., & Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accid. Anal. Prev., 38*(3), 610–617.

Liu, S., Wang, J., & Fu, T. (2016). Effects of lane width, lane position and edge shoulder width on driving behavior in underground urban expressways: A driving simulator study. *Int. J. Environ. Res. Public Health, 13*(10), 1010–1013.

Lundkvist, S. O., Ytterbom, U., & Runersjoe, L. (1990). *Continuous edgeline on nine meter wide two-lane roads, Report, 23*. Linkoping, Sweden: Swedish Road and Traffic Research Institute.

Maroney, S., & Dewar, R. (1988). Alternatives to enforcement in modifying the speeding behavior of drivers. *Transp. Res. Rec., 1111*, 121–125.

McFadden, D.L. 1974. Conditional logit analysis of qualitative choice behavior. In Frontiers in Econometrics, ed. P. Zarembka, 105-142. New York: Academic Press.

Ministerio de Obras Públicas y Urbanismo (MOPU). Norma de carreteras 8.2-IC. Marcas viales; Centro de 368 Publicaciones. Secretaría General Técnica. MOPU: Madrid, Spain, 1987; ISBN 84-7433-456-X.

Montella, A., Aria, M., D'Ambrosio, A., Galante, F., Mauriello, F., & Pernetti, M. (2011). Simulator evaluation of drivers' speed, deceleration and lateral position at rural in-tersections in relation to different perceptual cues. *Accid. Anal. Prev., 43*, 2072–2084.

National Academies of Sciences, Engineering, and Medicine, 2004. A Guide for Reducing Collisions on Horizontal Curves. Washington, DC: The National Academies Press. https://doi.org/10.17226/13545.

Park, E. S., Carlson, P. J., Porter, R. J., & Andersen, C. K. (2012). Safety effects of wider edge lines on rural, two-lane highways. *Accid. Anal. Prev., 48*, 317–325.

Retting, R. A., & Farmer, C. M. (1998). Use of pavement markings to reduce excessive traffic speeds on hazardous curves. *ITE Journal (Institute of Transportation Engineers), 68*(9), 30–34.

Retting, R. A., McGee, H. W., & Farmer, C. M. (2000). Influence of experimental pavement markings on urban freeway exit-ramp traffic speeds. *Transp. Res. Rec., 1705*, 116–121.

SEOPAN and AEC, 2017. Seguridad en carreteras convencionales: un reto prioritario de cara al 2020. Available at: https://seopan.es/wp-content/uploads/2016/03/Informe-AEC_Seguridad-carreteras-convencionales_A4.pdf.

StataCorp.2021. Stata Manual: xtmlogit: Fixed-effects and random effects multinomial logit models. College Station, TX: StataCorp LLC. Available at: https://www.stata.com/manuals/xtxtmlogit.pdf.

World Health Organization, 2018. Global status report on road safety 2018.

Wulff, J. N. (2015). Interpreting results from the multinomial logit model: Demonstrated by foreign market entry. *Organiz. Res. Methods, 18*(2), 300–325.

Yu, J., Xu, L., Liu, Q., & Qin, J. (2015). Transverse rumble strips design and comfort evaluation at arterial highway unsignalized intersection. *Journal of Wuhan University of Technology (Transportation Science and Engineering), 39*(1), 135–143.

Zhang, L., Liu, T., Pan, F., Guo, T., & Liu, R. (2014). Analysis of effects of driver factors on road traffic accident indexes. *China Saf. Sci. J., 24*(5), 79–84.