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Identification and Comparative Safety Analysis of Overtaking Patterns on Two-Lane Highways: A Simulator Study With Novice Drivers Peer-reviewed author version

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- 29 Keywords: Novice drivers, Two-lane highway, Overtaking patterns, Comparative safety evaluation.
- 30 31

1 ABSTRACT

2

Overtaking on two-lane highways is one of the riskiest driving maneuvers. However, safety analysis technologies for overtaking patterns and trajectories require development. In this simulator study, 328 overtaking trajectories were collected from 52 novice drivers to analyze difference in overtaking safety performances on two-lane highways under different traffic conditions. Two analyses were conducted:

7 Analysis I focused on structural trajectory differences and classified the trajectory sample into two patterns

8 — "ladder" (LAT) and "triangle" (TRT). In Analysis II, a comparative safety evaluation method was
9 established based on data envelopment analysis to compare overtaking pattern safety; a factor analysis of

10 the safety performance was undertaken by means of ordinary regression models. We found that TRT had a

11 lower spatial consumption and smoother trajectory than LAT, but drivers overtaking using TRT were

12 exposed to higher risk than LAT. Certain environmental and human factors had an influence on the safety

13 levels of the patterns: both deteriorated when drivers were surrounded by vehicles driving at higher speeds, 14 and improved with longer passing sight distances. However, safety levels when overtaking trucks were

15 significantly worse than overtaking cars in the LAT pattern — the opposite was found for TRT. Female

16 drivers' safety performance was superior in the LAT pattern; no significant gender difference were found

17 with TRT. A longer following distance was found to ameliorate the safety of the TRT pattern, with no effect

18 on LAT. These findings aid understanding of overtaking maneuvers on two-lane highways, and provide

19 recommendations for advanced assistance driving and automatic driving systems.

20 Keywords: two-lane highway, overtaking maneuver, safety, behavioral safety analysis and factor analysis

1 INTRODUCTION

2 Although great efforts have been made to improve road safety worldwide in recent years, the number of fatalities is still very high in many countries (1). Taking China as an example, 62,767 deaths, 3 4 256,101 injuries, and 13.46 billion (U) in property loss resulted from traffic crashes in 2020, of which 5 86.8% were caused by motorized vehicles (2). The death rate per million people is 16.6 in China (1). For some time, the complexity of the road environment (i.e., road geometry and traffic flow) and heterogeneous 6 7 driver behavior have been the two main causes of road crashes considered (3). According to different quality 8 of service requirements, the road system in China is divided into four grades: the low grade highways (i.e., 2nd, 3rd, and 4th grades) account for 89.6% of the total mileage, and the high-grade highways (i.e., 9 expressways and 1st grade) with multilane roads represent the minority (4). At the same time, there is an 10 average annual growth of nearly 25 million novice drivers and 30 million new cars being registered (5). 11 12 The continuous growth of the population of novice drivers has put more pressure on road safety. Two-lane 13 highways are widespread worldwide, and overtaking crashes on such roads can result in the most serious consequences (6, 7). In China, the highest mortality rate for traffic crashes is on 2nd grade highways with 14 15 two-lane roads: about 2 to 3 times that of other road categories. Novice drivers are more likely to commit traffic violations, and their vehicle crash rate is twice that of their older and more experienced counterparts 16 17 (8-10). Therefore, a better understanding of novice drivers' behavior on two-lane highways would help to 18 improve road safety.

19 Previous research on overtaking has resulted in two main contributions. One stream of research has 20 focused on the structural properties of overtaking maneuvers, resulting in various overtaking classifications. 21 Early work was mainly descriptive in nature and laid the foundations for the classification of overtaking maneuvers as a function of properties such as duration, distance, and speed in relation to the overtaken 22 23 vehicle (11-13). For instance, Prisk examined single passing maneuvers, and classified these into four types: delayed start, hurried return, delayed start and hurried return, and free moving with no opposing 24 traffic (13). Based on this work, multistage analyses of overtaking maneuvers became popular (14, 15). For 25 example, Jenkins and Rilett modeled overtaking as a five-stage phenomenon in which the overtaking 26 27 vehicle (1) initiates the maneuver and begins to enter the opposing lane, (2) is inside the opposing lane, (3) moves abreast of the impeding vehicle, (4) initiates entrance into the origin lane, and (5) is fully situated 28 back in the origin lane (14). Through comparison of acceleration in the five stages, flying- and accelerating 29 30 overtaking strategies were identified. Later work simplified the five stages with a three-stage model 31 consisting of lane-change, overtake, and merge, becoming the most commonly used model to study 32 overtaking maneuvers (16–20). Vlahogianni further reduced overtaking maneuvers, resulting in only two stages: the acceleration phase and the back-to-lane phase (21). More recent work on undivided roads in 33 34 India found that overtaking maneuvers can structurally differ depending on the traffic conditions (22, 23). These studies provided the first tentative indications that the execution of overtaking maneuvers varies as 35 36 a function of road- and traffic conditions, rather than overtaking being a maneuver that is structurally executed in a consistent manner across situations. However, further validation of this is required. 37

38 A second research avenue was less focused on descriptive classifications and more oriented toward 39 (1) observation of critical safety performance indicators during overtaking (e.g., overtaking gap acceptance, 40 vehicle speed, time and distance traveled in the opposite lane); (2) identification of factors determining the safety performance of overtaking maneuvers; and (3) prediction of safety performance indicators as a 41 function of road geometry, traffic conditions, and driver characteristics. Different research methods and 42 43 data collection techniques were used for that purpose, including videography (22, 24), driving simulation (14, 21, 25–27), and the use of instrumented vehicles equipped with different types of sensors (23, 28). 44 45 Videography made it possible to obtain, screen, and analyze massive quantities of noisy driving data in fixed points. Llorca and Gracia observed overtaking maneuvers on existing highways by means of six video 46 47 cameras installed on fixed points next to sections where overtaking was allowed (24). The authors found that the type and speed of the impeding vehicle were the factors that most strongly influenced the time and 48 distance traveled in the opposite lane. Rahul et al. used an instrumented vehicle that was equipped with 49 50 LiDAR and video cameras (23). Overtaking data on divided four- and undivided two-lane roads in India 51 were collected, and a new variable, "excess distance" (i.e., the extra distance covered by an overtaking

vehicle compared with the overtaken vehicle), was introduced in the analysis of observed overtaking events. 1 2 The results indicated that the presence of oncoming vehicles and the type of overtaken vehicle had a large 3 and statistically significant impact on overtaking. Farah et al. used a driving simulator to study overtaking (25). The authors developed a prediction model that showed that vehicle speed, following distance, road 4 5 geometry, and driver characteristics (i.e., gender and age) significantly affected gap acceptance in 6 overtaking. Llorca and Farah compared two data samples, that is, one collected via driving simulation and 7 another by means of an instrumented vehicle to validate the results obtained from the simulator (26). They 8 found that the overtaking time, distance, and gap acceptance observed in the simulator were similar to those observed with the instrumented vehicle. Figueira and Larocca also compared data from a simulator study 9 10 with data collected in a naturalistic setting, but focused on eye movements and glance behavior during overtaking (27). The drivers' eye behavior patterns during the driving simulation were similar to those 11 12 observed in real overtaking situations.

13 In summary, previous work on overtaking has substantially improved our understanding of this particular maneuver. Several descriptive classifications have been proposed, and a variety of research 14 15 methods and data collection techniques have been used to observe critical safety performance indicators during overtaking, to identify factors determining the safety performance of overtaking maneuvers, and to 16 17 predict safety performance indicators as a function of road geometry, traffic conditions, and driver 18 characteristics. Notwithstanding, some important issues remain unexplored or need further validation. For instance, between-subject and cross-situational variance in overtaking maneuvers have been documented 19 20 in previous work, but corroboration of findings is required. Additionally, most available work has focused 21 on a selection of separate local safety performance indicators, rather than adopting a more integrated multiple risk sources approach to studying risk. Therefore, the objective of this study was to develop and 22 23 implement (in a moving-base high-fidelity driving simulator) a method of evaluating safety in overtaking maneuvers on two-lane highways. The focus was on young adult novice drivers as younger and more 24 inexperienced drivers have been found to overtake more frequently and in riskier ways compared with other 25 age groups (29). Specifically, the following three research questions (RQs) were proposed 26

27 RQ1: How are overtaking maneuvers on two-lane highways executed by young adult novice28 drivers, and what resulting spatial trajectories are followed?

RQ2: Does the safety performance of novice drivers executing overtaking maneuvers on two-lane
 highways differ as a function of structural differences in the trajectories?

RQ3: What factors determine the safety performance level of novice drivers executing overtaking
 maneuvers on two-lane highways?

The remainder of this paper is structured as follows: the METHODS section covers the methodological details of the data collection via the simulator experiment, and presents the safety evaluation method based on a comparative analysis. The RESULTS section is dedicated to data analysis procedures and results. The most important findings are discussed in the DISSCUSSION AND CONCLUSION section.

39 METHODS

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38

41 Experimental design

42 This study adopted a repeated measures within-subject design in which each participant was exposed to a 43 total of eight overtaking situations. To avoid learning effects, 10 parallel scenarios that randomized the order of the eight overtaking situations were produced. Each participant was assigned to one of the 10 44 scenarios and was required to complete all eight of the situations in the scenario. Each of the overtaking 45 situations was designed in relation to three factors (see Table 1 for an overview of these factors and their 46 47 respective discretization). These were (1) speed of the impeding vehicle (IMV: two conditions), (2) type of impeding vehicle (IMT: two conditions), and (3) speed of the opposite vehicle (OPV: two conditions). 48 Passing sight distance (PSD) was set at fixed levels in a previous study (27), which was limited to exploring 49 50 the effects of PSD on the safety performance of overtaking. Therefore, we adopted a compound design (see

51 Figure 1) for each situation, in which one IMV in the origin lane faced four OPVs in the opposite lane with

a gradually increasing intervehicular distance. The OPV drove past the ego vehicle if participants believed
that the current PSD was too short to overtake and continued following in that case. On the other hand,
participants executed overtaking with a PSD they deemed reasonable so that a continuous- rather than a
fixed-level PSD data set was collected.

5 6

Faators	Meaning		Discretization				
ractors			Rule			value	
IMN	The speed of impeding vehicle		Two speed levels that could block the			Slower: 30km/h	
IIVI V			traffic flow on the two-lane highway			Faster: 50km/h	
МТ	The type of impeding vehicle		Two common types of vehicles on			Passenger car (PC)	
1101 1			the two-lane highway			Truck (TR)	
OPV	OPV The speed of opposite vehicle		Two common speed levels on the			Slower: 40km/h	
01 V			two-lane highway		Faster: 60km/h		
					Dir	ection of Opposite Lane	_
k	Passing sight distance now		300m	400m	4	500m	→
			😐 .	4			E (1990)
Ego vehicle	Impeding Vehicle	Opposite Vehicle 1s	t Opposite Vehicle 2nd	Opposite	Vehicle 3rd	Opposit	e Vehicle 4th
		⇒					

TABLE 1 Factors used to design overtaking situations: definitions and discretization

Figure 1 Illustrative spatial sketch of the overtaking situation as included in the driving scenario

The scenario to which participants were exposed mimicked a typical Chinese two-lane highway. A lane width of 3.50m was adopted and shoulders were present. No intersections were included, but tangent sections 2 km in length were combined with left- and right-turning curves. The curve radius was 300m and no vertical crests were included to guarantee an accurate overview. The total length of the scenario was approximately 20 km, with eight tangent sections (S1 to S8), three right-turning curves (C1, C4, and C5), and four left-turning curves (C2, C3, C6, and C7) (see Figure 2).

17



18 19 20

Figure 2. Schematic overview of the driving scenario

21 Participants and apparatus

Direction of Origin Lane

- 22 Students from the Southeast University campus, Nanjing, were approached via a social media campaign,
- resulting in a total of 52 participants (33 males and 19 females). Five persons were withdrawn from the
- sample as they demonstrated slight 3D vertigo during the simulation, resulting in a final sample of 47

⁷ 8 9 10

1 participants (28 males and 19 females). Before the experiment, each participant was required to complete 2 the demographic and driving experience self-report survey. The age range was between 20 and 30 years 3 (mean=23.3, SD=2.017), and driving experience ranged from 1 to 7 years (mean=2.81, SD=1.77). The 4 total driving mileage of each participant is less than 10000 km. The study was conducted on the simulator 5 at the School of Transportation, Southeast University (see Figure 3), which runs the SCANeR driving 6 simulation software developed by INNO, France. Data were recorded at a 100Hz sampling rate. Among the 7 variables of interest were the x- and y-axis positions, speed, acceleration, and steering wheel angle. From 8 these, different performance indicators were calculated, such as overtaking time, distance, and speed.





11 12

13 Framework for data analysis

Analysis I: Structural Trajectory of Overtaking Maneuvers 14

The data analysis was subdivided into two parts. Analysis I focused on how overtaking maneuvers were 15 16 executed by the participants (cf. RQ1). In detail, as a first step, the vehicle heading angle was used to 17 examine the spatial trajectory followed by the participants while executing the overtaking maneuvers. In 18 line with previous work, overtaking maneuvers were considered to consist of three main stages: lane-19 change, overtake, and back-to-lane (see Figure 4). Four points of interest had to be determined, that is, lane-

- 20 change start, the transition from lane-change to overtake, the transition from overtake to back-to-lane, and
- 21 back-to-lane end.



22 23

Figure 4. Three main stages of an overtaking maneuver

As a second step, following Dario et al. (30), the time-course graphs of steering wheel angle and Y 24 position were plotted together with error bars to investigate whether there were any structural differences 25 26 in the way of overtaking maneuvers were executed. As a third step, a repeated measures multivariate 27 analysis of covariance (MANCOVA) was employed to investigate whether overtaking time, distance, and

- 28 the mean value as well as the variance of speed were statistically significantly different as a function of the 29
- structural differences in the execution of overtaking maneuvers. The null hypothesis, H_0 , for H_1 states that

the overtaking patterns of young novice drivers are consistent, and there is no significant difference in spatial characteristics between the patterns. The alternative hypothesis (Ha) states that different overtaking patterns can be found, and there is a significant difference in the spatial characteristics between the patterns (cf. RQ1). The H1 test was formulated as follows, *i* and *j* referring to a specific overtaking pattern, and Sc_i the spatial characteristic of pattern *i*:

6

7

 $H_0: Sc_i = Sc_j$ $H_a: Sc_i \neq Sc_j$

8 Analysis II: Comparative Safety Performance Assessment of Overtaking Maneuvers and Related
 9 Determinants

10 Analysis II focused on the level of safety performance of overtaking maneuvers, and whether the safety 11 performance differed as a function of the structural differences in the execution of overtaking maneuvers 12 (cf. RQ2). The second H_0 states that there is no significant difference in safety performance between the 13 patterns. The Ha states that there is a significant difference in safety performance between the patterns (cf. 14 RQ2). The H_2 test was formulated as follows: *i* and *j* refer to the different overtaking patterns, and Sl_i the 15 safety level of pattern *i*:

- 16
- 17
- 18

/

In addition, which factors determine the level of safety performance of overtaking maneuvers (cf. RQ3) were also explored. We proposed the third hypothesis (H3) with H0 as follows: the effects of human and environmental factors on the safety performances of different patterns are consistent. Ha states that the effects of human and environmental factors on the safety performances of different patterns are inconsistent (cf. RQ3). The H_3 test was formulated as follows: *i* and *j* refer to the different overtaking patterns, and Ef_i denotes the effects of human (e.g., gender, PSD, and following distance) and environmental (e.g., speeds of the IMV and OPV, and IMT) factors on pattern *i*:

 $H_0: Sl_i = Sl_j$

 $H_a: Sl_i \neq Sl_i$

- 26
- 20 27

 $H_0: Ef_i = Ef_j$ $H_a: Ef_i \neq Ef_i$

The rationale for the safety assessment of overtaking performance was derived from previous studies, albeit those that examined safety performance indicators in isolation rather than considering them in combination. Figueira and Larocca showed that rear-end and frontal collisions are among the most common crashes on two-lane highways (27). Ma and Hui argue that oblique collisions with the IMV and lane exceedance during the lane-change stage are two additional safety risks when overtaking (31). Therefore, these four crash risks were included in this study to determine the safety performance of overtaking maneuvers.

For the mathematical calculation of safety, data envelopment analysis (DEA) was used, specifically 35 36 Charnes, Cooper, and Rhodes' (CCR) model. This was to allow the creation of one comprehensive score 37 for safety performance (32). To determine whether the safety performance indicators differed as a function of the structural differences in the execution of overtaking maneuvers, a repeated measures MANCOVA 38 39 was conducted. Moreover, multiple linear regression (MLR) analysis was used to identify factors 40 determining the level of safety performance of overtaking maneuvers. Before presenting the results of 41 Analyses I and II, the next section covers the composition of the comprehensive score of safety performance 42 for overtaking maneuvers.

43

44 Numerical Modeling of a Comprehensive Score of Safety Performance for Overtaking Maneuvers

45 As explained, DEA, specifically the CCR model, was used for the calculation of a comprehensive safety

46 score to assess overtaking maneuvers. Four crash types (i.e., rear-end, frontal, oblique, and off-road) were

47 considered in the evaluation. In Figure 5, the points where one of these crash types could occur are marked

48 in yellow for each of the three stages of an overtaking maneuver. It is worth mentioning that the outer

49 contour points of the vehicle, instead of the centroid, were used to determine the exact potential crash spots.

50 In this study, the size of the car model was 4.9×1.8 m and the truck model was 9.6×2.4 m.

1



Some of the most widely used surrogate safety indicators for crash risk assessment are Time-to-8 collision (TTC), Time exposed TTC (TET), and Time integrated TTC (TIT) (34, 35). Yet, these TTC 9 indicators are more suitable for vehicle conflicts in the same lane, such as in car following situations (36, 10 37). For the conflict of lane-change, the calculation of TTC is made after decomposing the X/Y coordinate, which led to excessive calculation. Hence, the instantaneous Time Difference to Collision (TDTC) was 11 12 used to determine the risk for each time point of the overtaking trajectory (see Figure 6 (a)). It actually represents the time difference between two vehicles passing through the conflict point at each time point 13 (38). Based on time integrated TDTC (TITC), the risk score from each potential conflict point can be 14 15 obtained (see Figure 6 (b)). As for the selection of the TDTC threshold, not enough crash data was available to determine the risk level, so we refer to the Post encroachment time (PET) threshold value used in previous 16 17 studies since the TDTC can be considered as a derivative of PET. Zheng et al. illustrated that the PET threshold decreases with the increase of road design speed (38). In a pedestrian and left-turning conflict 18 study, 3 to 6 s was the threshold used (39), and 1 to 1.5 s in a study of crash risk on expressways (40). The 19 20 design speed of two-lane highways is commonly at 60 to 80 km/h, which is between that of the urban road intersection and expressway. Therefore, according to the results of the sensitivity analysis, we took 2 s to 21 be the TDTC threshold in this study, to calculate the TITC value. Figure 7 depicts the nine potential risk 22 23 measurements in the three stages of overtaking, and Table 2 gives a more detailed overview of how risk 24 scores for each of the nine different conflict points were calculated.

25



26 27

Figure 6. Time integrated time difference to collision (TDTC): (a) Instantaneous TDTC value, (b) 28

29 Time integrated TDTC.



1 2 3 X6: Ego vehicle & Impeding vehicle

X9: Ego vehicle & Road right side

Figure 7. Nine conflict points: (a) lane-change stage, (b) overtake stage, and (c) back-to-lane stage. Table 2. Calculation of Risk Scores for the Nine Conflict Points

$$TDTC(x_1) = \frac{S_1}{V_{ego}} - \frac{0}{V_{IMV}} \qquad TDTC(x_4) = \frac{S_4}{V_{ego}} \qquad TDTC(x_7) = \frac{S_{7e}}{V_{ego}} - \frac{S_{7o}}{V_{opv}}$$
$$TDTC(x_2) = \frac{S_{2e}}{V_{ego}} - \frac{S_{2o}}{V_{IMV}} \qquad TDTC(x_5) = \frac{S_{5e}}{V_{ego}} - \frac{S_{5o}}{V_{opv}} \qquad TDTC(x_8) = \frac{S_{8e}}{V_{ego}} - \frac{S_{8i}}{V_{imv}}$$
$$TDTC(x_3) = \frac{S_3}{V_{ego}} \qquad TDTC(x_6) = \frac{S_{6e}}{V_{ego}} - \frac{S_{6i}}{V_{imv}} \qquad TDTC(x_9) = \frac{S_9}{V_{ego}}$$
$$TITC(X_i) = Time integrated TDTC(x_i) = \int_{t_1}^{t_2} x_i \, dt, i = 1, 2, ..., 9$$

4 5 Note: TDTC = time difference to collision; t_1, t_2 represent the start and end points of a time interval in which the instantaneous TDTC value is lower than the threshold (cf. Figure 6).

6 Figure 7. Nine conflict points: (a) lane-change stage, (b) overtake stage, and (c) back-to-lane stage.

7 The final step was to compose a comprehensive risk value, that is, a value that would allow the 8 estimation of the safety performance of overtaking maneuvers by accounting for the risk associated with 9 the potential conflict points. The TITC was a definite integral based on time series (i.e., delta t) so that the 10 risk value would be higher if the overtaking time was longer. Hence, it was affected by the length of time. 11 Therefore, in this study, the comprehensive risk value aggregated from the nine TITCs per time unit was taken as the final value for the assessment. The CCR model was used for that and is presented by Equations 12 1 to 4. The objective function of the model is to minimize the comprehensive risk value of each overtaking 13 14 maneuver. The model is subject to the following constraints: 1) the risk values of all maneuvers should not be lower than the benchmark value of 1, and the case with a value of 1 corresponds to the safest maneuver 15 16 in this sample; and 2) the value of all weight variables should be equal to or greater than 0. The 17 comprehensive risk value for each maneuver was calculated by Equations 1 to 4. The lower the value, the 18 better the safety.

$$Y_{ik} = \frac{X_{ik}}{T_k} \tag{1}$$

20 where

19

 X_{ik} refers to the TITC of the potential conflict point *i* of the driver *k*, 21

 T_k refers to the time duration of overtaking maneuver k, 22

 Y_{ik} refers to the value of TITC per time unit of the conflict point *i* of the maneuver *k*.

$$\min Risk_{o}^{U} = \sum_{i=1}^{m} v_{i} \times Y_{io}$$
(2)
s.t. $\{\sum_{i=1}^{m} v_{i} \times Y_{ik} \ge 1, k = 1, 2, 3, ... n$ (3)
 $v = (v_{1}, v_{2}, ..., v_{i}, ..., v_{m})^{T} \ge 0$

4 Where m and n refer to the number of potential conflict points and overtaking maneuvers, 5 respectively; and v_i refers to the weight of the score of the conflict point, i.

(4)

$$Risk value_{o} = Risk_{o}^{U*}$$

Where $Risk_k^U$ refers to the comprehensive value of maneuver k.

9 **RESULTS**

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6 7

8

1 2 3

11 Analysis I: Structural Trajectory of Overtaking Maneuvers

A total of 328 overtaking maneuvers were executed in this study. As already explained, overtaking maneuvers were assumed to consist of three consecutive stages: lane-change, overtake, and back-to-lane. To empirically validate this assumption, scatter plots of x- and y-axis coordinates were created to replicate the structure trainecture of the sharehold exected in the structure of the structu

15 the structural trajectory of the observed overtaking maneuvers (see Figure 8).





Figure 8. Scatter plots of x- and y-axis coordinates of overtaking trajectories: (a) 'Traiangle' type,
 (b) 'Ladder' type.

20 We then investigated the distribution of constant duration of the heading angle after the lane change stage (see Figure 9), and found that 0.5 s significantly divided the 328 trajectories into two categories. 21 Therefore, two overtaking trajectories, the "triangle" type (TRT) and the "ladder" type (LAT), were 22 23 identified based on the classification of heading angle after the lane-change stage. If the heading angle remained constant along the lane direction for less than 0.5 s after the lane-change stage, the trajectory was 24 25 regarded as TRT, otherwise it was regarded as LAT. Therefore, 143 observed maneuvers were classified 26 as TRT and 185 as LAT. To further explore differences between TRT and LAT, the data sample was split 27 into two subsamples according to the trajectory followed. As in Dario and Liu (30), time-course graphs of 28 steering wheel angle and y-position were plotted together with the error bars (see Figure 10). To that purpose, aggregated data were used, that is, mean value sequences were obtained through segmentation of 29 30 trajectory data into standardized units of time. Specifically, data for steering wheel angle and y-position 31 were first turned into 50 standardized unit sequences with the mean value for each unit of sequences calculated to form trend point sequences. 32



33 34



4

2 3

1

Figure 10. The time-course graphs of steering wheel angle and Y position

5 To clarify understanding of the steering wheel angle graphs, participants turned to the left when the 6 steering wheel angle was greater than 0, and to the right when the steering wheel angle was less than 0. In 7 the case of LAT, participants firstly turned the steering wheel to the left to enter the opposite lane, and 8 subsequently kept the steering wheel stable for a certain period of time to stay in the opposite lane and 9 overtake the IMV. Afterwards, they returned to their original lane. In the case of TRT, drivers turned the 10 steering wheel to the left to enter the opposite lane, but directly turned the steering wheel to the right to 11 return to the original lane. From the graph representing the y-position (Figure 10b), a clear "transition" 12 section can be observed in the case of LAT, but not for TRT. In addition to steering wheel angle and yposition, time duration, distance, average speed, and speed variance were compared between LAT and TRT. 13 14 These parameters were the dependent variables in a repeated measures MANCOVA, and speed of the IMV, 15 IMT, speed of the OPV, and PSD were entered as covariates to control for traffic conditions. The results 16 are presented in Table 3; all tests were performed at the 0.05 level of significance.

17 Based on the data in Table 3, we can reject H_0 for H_1 as it can be observed that, for the complete maneuver, duration and distance were both statistically significantly different with a longer duration and 18 19 distance for LAT than TRT. This was anticipated since execution of LAT entails completion of a second "transitioning" stage whereas this is not the case for TRT. As for the speed-related variables, average 20 speed was significantly higher for TRT in total. Overall, it seems that LAT was a more conservative way 21 22 of overtaking compared with TRT. Analysis II proposes a more formal assessment of the safety 23 performances of LAT and TRT.

24 25

TABLE 3. Results for repeated measures MANCOVA

Variables	Definition	LAT Num = 185	TRT Num = 143	F	Sig.
T _{total}	Duration of the overtaking maneuver	13.733	10.763	21.638	<.001
D _{total}	Distance of the overtaking maneuver	249.742	201.241	20.452	<.001
AS _{total}	Average speed of the overtaking maneuver	18.968	19.618	4.846	.028
VS _{total}	Speed variance of the overtaking maneuver	22.327	22.568	1.406	.237

²⁶

27	Analysis II: Comparative safety performance assessment of overtaking maneuvers and re	elated
28	determinants	

29 As a first step, we obtained the comprehensive safety value of the trajectories of each overtaking pattern

based on DEA. $Mean_{LAT} = 1.6426$ and $Mean_{TRT} = 1.8321$ (The mean risk values of two patterns), we 30

have to refuse the null hypothesis H₀ of H2. Speed of the impeding vehicle, type of impeding vehicle, speed 31

32 of the opposite vehicle, and passing sight distance were entered as covariates to control for traffic

33 conditions. From the results of repeated measures MANCOVA, we found that risk value for the TRT is

significantly higher compared to that of LAT (F=5.258 and p=0.022, [significant at 0.05 level]). It indicates 1 2 that an overtaking behavior as TRT was really a riskier behavior choice compared to LAT.

3 Secondly, there are still environment and human factors affecting novice drivers' behavior in this 4 experiment. We considered six factors of human aspects and environment, as potential factors in the MLR 5 models. The speed of the impeding vehicle (IMV), the type of the impeding vehicle (IMT) and the opposing 6 vehicle (OPV) are three presupposed traffic environment variables. Gender (GEN), the choices of passing 7 distance (PSD) and following distance (FD) are three human-related factors.

8 The results of MLR models are listed in **TABLE 3**, all tests were performed at the 0.05 level of significances. We have to refuse the null hypothesis H₀ of H3. In the LAT pattern, three presupposed 9 environment factors all have a significant impact on the "Ladder type" overtaking maneuver. When novice 10 drivers faced a higher speed of other vehicles or overtaking a truck, their risk value increased. In the 11 12 perspective of human factors, the safety attribute of their overtaking maneuvers would be better when they 13 choose a longer PSD. But different initial positions (FD) do not affect the safety of the LAT. Moreover, the 14 safety of male drivers' LAT overtaking is statistically worse than that of female drivers.

15 In the TRT pattern, the three presupposed environment factors still have a significant impact on the 16 "Triangle type" overtaking maneuver. But the opposite result occurred with respect to IMT. The risk value 17 of overtaking a truck is lesser than that of overtaking a car. In terms of safety, accepting a longer PSD is 18 always good. Besides that, to keep a longer following distance before overtaking is also effective to reduce 19 risk values. There are no significant differences in safety attribute between males and females to perform 20 TRT.

2	1

TABLE 4.	Results fron	n the MLR	models on	the safety	performance
				•	1

	LAT		TRT		
	B (Unstandardized)	Sig.	B (Unstandardized)	Sig.	
IMV	.031	<.001	.038	<.001	
IMT	.220	.036	264	.022	
OPV	.022	<.001	.013	.025	
GEN	.250	.023	012	.920	
PSD	485	<.001	515	<.001	
FD	.000	.126	001	.012	
R ²		0.395		0.372	

22 23 24 Note: LAT = ladder type; TRT = triangle type; Sig. = significance; IMV= the speed of impeding vehicle; OPV = the speed of opposite vehicle; IMT= the type of impeding vehicle; GEN=gender; PSD= passing distance; FD= following distance.

*p<.05

25 **DISCUSSION AND CONCLUSION**

26 Compared with other types of accidents, the outcomes caused by overtaking on two-lane highways 27 are among the most serious, as this type of overtaking risks highspeed frontal collisions with vehicles in the 28 opposite lane (7). Drivers need be vigilant of the traffic environment to determine appropriate opportunities to drive into and out of the opposite lane. Several factors can increase the overtaking risk during this 29 30 complex, multistage maneuver, especially for novice drivers. In this study, we investigated the overtaking behavior of young novice drivers on two-lane highways via a driving simulator experiment. Two overtaking 31 patterns-LAT and TRT-were firstly distinguished from the perspective of structural differences in 32 33 trajectory (cf. RQ1). We found significant differences in spatial characteristics and steering wheel operation after the lane-change. Drivers demonstrating TRT overtaking, that is, smoother turning and faster speeds, 34 35 would complete the maneuver in a more efficient way (shorter time and distance) than those employing 36 LAT. Pattern differences have rarely been addressed in previous studies, only acceleration differences (i.e., 37 accelerating or flying overtaking patterns [14]) and overtaking side (i.e., from the left or right side [23]) were considered by safety analysts. However, confusion surrounding different patterns of driving behavior 38 39 in analyses could mask their difference. Therefore, the cooperative control of throttle and steering wheel following the lane-change was explored in this study, and proved to be a good indication of overtaking 40 pattern discrimination. However, the significant spatial differences between the two patterns should not be 41

ignored as potential predictors of overtaking characteristics. 42

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In addition to the spatial characterization, evaluation of the safety performance of overtaking 1 2 trajectories is another contribution of this study. Evaluation of local risk, such as rear-end- and frontal 3 collisions, was the main objective in previous studies, which were limited by risk measurement methods. 4 There is still plenty of room for improvement in the comprehensive risk characterization of overtaking on 5 two-lane highways. Nine potential risk conflicts in different stages were considered, and the indicators of 6 TITC of these risk sources were aggregated into a comprehensive risk score based on DEA. Thus, further 7 investigation of a driver's risk level at each potential conflict point to identify his/her behavioral 8 intervention focus was possible. From comparisons between the two patterns, we found that novice drivers employing TRT overtaking were exposed to statistically significantly higher risk than those using the LAT 9 pattern (cf. RO2). This was in line with expectations that aggressive driving would be accompanied by 10 higher risk. The cooperative throttle and steering wheel operations of the TRT after the lane-change were 11 12 the main reasons for this higher risk. The faster average speed is likely to increase the risk of a frontal 13 collision. Furthermore, a smoother trajectory represents a closer return with the IMV from the opposite lane, which could lead to a significant increase in side crashes. Therefore, we believe that a driver's choice of 14 15 overtaking pattern could be considered an external manifestation of their risk preference. The LAT pattern could be considered a more conservative, textbook way of overtaking; possibly these novice drivers were 16 17 unable to determine an appropriate opportunity by which to drive into and out of the opposite lane. Conversely, the TRT might be considered more "aggressive" and skillful, on account of novice drivers 18 who, in that case, adopted a faster speed and more skillful throttle and steering wheel cooperation. However, 19 20 this does not mean that novice drivers should follow either a TRT or LAT pattern when overtaking, each 21 pattern has its own strengths and weaknesses. We believe novice drivers should select the overtaking pattern that is right for the specific situation. 22

23 Having explored the heterogeneity in the spatial and safety performances of the two patterns, we further explored the human- and traffic environmental factors affecting the risk values of these two 24 overtaking patterns (cf. RO3). We found that the risk values of both increased when drivers faced IMVs or 25 OPVs driving at higher speeds. This finding is in line with the results of research by Figueira and Larocca 26 27 (27). It is more difficult for novice drivers to decide whether to overtake or not, when the surrounding 28 vehicles are traveling at a higher speed. It would be better for novice drivers to overtake in a LAT pattern in challenging conditions as the risk value increment of the TRT pattern is more sensitive to the speed 29 change of surrounding vehicles; conversely, TRT would be preferable under more straightforward 30 31 conditions for the same reason. We found that the IMT had a different effect on the safety performances of 32 the two patterns. The LAT results were the results are consistent with the results of previous studies, which 33 indicated that the truck, with high occupation of road source and sight impact on the ego vehicle, 34 significantly increased the risk of overtaking. The opposite result was found in the TRT pattern. One possible reason for this could be that the TRT is a faster and smoother way of completing overtaking: novice 35 36 drivers might have the confidence to overtake a small car, but be more cautious when overtaking a truck. This indicates that novice drivers who prefer overtaking trucks using a TRT pattern are likely to be more 37 sensitive to traffic-related environmental information provided by an advanced driving system. Human 38 39 factors were also found to significantly affected the safety performances of the two patterns. In the LAT 40 pattern, the safety performance of male novice drivers was statistically worse than that of female drivers; this result was consistent with the conclusion that male drivers have a stronger risk preference than female 41 drivers (29). However, no significant safety differences were found between the male and female groups 42 43 who overtook using the TRT pattern. It seems that overtaking in this more "skillful" way (i.e., TRT), effectively eliminated any gender-related differences in safety performance. The conservative, textbook 44 method (i.e., LAT), exposed more driving deficiencies in males. The safety performance of both patterns 45 was affected by PSD, which indicates that guiding drivers to overtake with an appropriate PSD would be a 46 47 good means of improving safety. In addition, FD before overtaking was found to be important for safe overtaking using TRT, but had no effect on LAT. The LAT pattern involves taking an earlier position, 48 further away from the IMV, before driving into the opposite lane, which weakened the effect of the FD 49 value. Conversely, drivers in the TRT case would select a more advanced position, closer to the IMV, which 50

1 was sensitive to the FD value. Optimization of the FD determinant could be the key improvement for the2 TRT case.

In summary, by distinguishing between two overtaking patterns (i.e., LAT and TRT), assessing the 3 4 overall risk of potential conflict points in each pattern, and further comparing influencing factors between 5 these two patterns, this study has provided valuable insights into how young novice drivers execute overtaking maneuvers on two-lane highways, their safety performance level, and the potential determinants 6 7 of their behavior. Firstly, we have to emphasize that observation of the differences in trajectory, from the 8 perspective of micro-operations, was meaningful. The two overtaking patterns-LAT and TRT-cannot be ignored in behavioral studies, as the differences in safety performance and factor exploration would be 9 affected were the overtaking patterns not clearly distinguished. Secondly, overtaking on two-lane highways 10 is a multistage behavior comprising multiple risk sources. It is therefore essential to assess safety 11 12 performance from the perspective of overall risk rather than solely local risk, as this could provide 13 assistance for Advanced Driving Assistance System (ADAS) and automatic driving technology to optimize overtaking behavior. Lastly, impact factor heterogeneity of the two patterns merits attention. We believe 14 15 that the aspects discussed are significant for active intervention in novice drivers' overtaking behavior, such as the design of an advanced driving assistant system that is able to manage each pattern according to its 16 17 merits. However, despite promising results, this study had some limitations that should be considered in 18 future research. Although the sample of novice drivers was suitable for our study, certain demographic variables need further exploration, such as age and driving experience. A larger data set containing more 19 20 demographic groups will be the focus of future work. Another limitation was that the structural differences 21 in overtaking trajectories were only observed from qualitative analyses (i.e., speed choice and steering wheel operation after lane-change). A greater range of micro-operations within the different stages of 22 23 overtaking should be considered, such as returning opportunities from the opposite lane, which could be meaningful for behavior prediction and characteristics analysis. Finally, the comprehensive safety 24 evaluation method is built on a relative risk theory. Therefore, an absolute risk judgment method could be 25 26 key to enhancing the applicability and practicability of future research.

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28 Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: R. Zhang, Y. Shen;
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