How much space do drivers provide when passing cyclists? Understanding the impact of motor vehicle and infrastructure characteristics on passing distance

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ABSTRACT:

Background: Understanding factors that influence the distance that drivers provide when passing cyclists is critical to reducing subjective risk and improving cycling participation. This study aimed to quantify passing distance and assess the impact of motor vehicle and road infrastructure characteristics on passing distance.

Methods: An on-road observational study was conducted in Victoria, Australia. Participants had a custom device installed on their bicycle and rode as per their usual cycling for one to two weeks. A hierarchical linear model was used to investigate the relationship between motor vehicle and infrastructure characteristics (location, presence of on-road marked bicycle lane and the presence of parked cars on the kerbside) and passing distance (defined as the lateral distance between the end of the bicycle handlebars and the passing motor vehicle).

Results: Sixty cyclists recorded 18,527 passing events over 422 trips. The median passing distance was 173cm (Q1: 137cm, Q3: 224cm) and 1,085 (5.9%) passing events were less than 100cm. Relative to sedans, 4WDs had a reduced mean passing distance of 15cm (Q1: 12cm, Q3: 17cm) and buses had a reduced mean passing distance of 28cm (Q1: 16cm, Q3: 40cm). Relative to passing events that occurred on roads without a marked bicycle lane and without parked cars, passing events on roads with a bike lane with no parked cars had a reduced mean passing distance of 27cm (Q1: 25cm, Q3: 29cm), and passing events on roads with a bike lane and parked cars had a mean lower passing distance of 40cm (Q1: 37cm, Q3: 43cm).

Conclusions: One in every 17 passing events was a close (<100cm) passing event. We identified that on-road bicycle lanes and parked cars reduced passing distance. These data can be used to inform the selection and design of cycling-related infrastructure and road use with the aim of improving safety for cyclists.

INTRODUCTION

Cycling as an active mode of transport has numerous health, environmental and social benefits. [1-3] For example, commuting by bicycle is associated with a 41% lower risk of all-cause mortality and 45% lower risk of cancer incidence.[2] However, cycling injuries are on the rise[4] and a large proportion of these involve collisions with motor vehicles.[5]

To increase participation, there is a need to address key barriers to cycling. Prior studies have noted that traffic conditions and motor vehicles driving closely to cyclists heighten subjective risk and create a barrier to cycling participation.[6-9] Therefore, quantifying how close motor vehicles pass cyclists and identifying the characteristics of close passing events provides an opportunity to develop interventions that address key barriers to increased cycling participation. Prior studies of passing distance have typically been conducted using a single instrumented bicycle on a set route,[10-13] using data collected only on a single cyclist,[14] or have used a limited number of fixed traffic cameras to estimate passing distance,[15] thus limiting the generalisability of these findings. Naturalistic driving studies have also been used to study the lateral distance that vehicles provide when passing cyclists, but have been limited to a small number of passing events,[16] or have used surrogate measures of passing distance, such as the distance to the bicycle lane marking, rather than quantifying lateral passing distance.[17] Using a device that can be fitted to any bicycle and enabling cyclists to self-select their route may alleviate some of the limitations of prior studies. To address this knowledge gap, we developed a purpose-built, on-bike device that measures the distance that motor vehicles provide when passing cyclists. Using this technology, this study aimed to quantify passing distance and assess the impact of motor vehicle and road infrastructure characteristics on passing distance.

METHODS

Study design

An on-road observational study was conducted in Victoria, Australia. A screening survey was used to identify potential participants. Eligible participants provided consent to be involved in the study, had a custom device installed on their bicycle and rode as per their usual cycling for one to two weeks. Data collection occurred between April and August 2017.

Ethics

Ethical approval for the study was obtained from the Monash University Human Research Ethics Committee (CF16/2348 – 2016001181).

Inclusion criteria

A screening survey was used to identify eligible participants. The screening survey was promoted through Monash University social media accounts. The screening survey asked about age, sex, bicycle type, cycling experience, percentage of a usual ride spent on-road, number of times riding a bicycle per week, purpose of the majority of riding and geographical region. Based on this information, purposive sampling was used to recruit cyclists who rode mostly on-road (>60% of an average trip), were located in metropolitan Melbourne (and distributed across metropolitan Melbourne) and rode more than two times per week.

Quantifying passing distance

A purpose-built, on-bike device was developed for the purposes of this study. This device, named the MetreBox, utilised the following technology: Adruino microprocessor (Adafruit Feather M0 Adalogger); Global Positioning System (GPS) sensor (Adafruit Ultimate GPS FeatherWing) that recorded at 1 Hz; ultrasonic sensor (XL-MaxSonar-EZ3 MB1230, Maxbotix, Minnesota, USA) that recorded at 10 Hz; and lithium ion 18650 hard case battery with voltage protection (Core Electronics).

A custom designed hard case was created with a 3D printer. The device was charged using a micro USB cable and data were stored on a micro SD card. Validation of the ultrasonic sensor was performed using a flat wall and each MetreBox was tested at 100cm and 200cm ranges, accuracy of each individual sensor varied. Each MetreBox was individually tested and calibrated, resulting in a measurement accuracy of +/- 1.5cm. The device had a measurement range of 0cm to 330cm.

Device installation

Device installation was performed by a study research assistant. The MetreBox device was installed on each participant's own bicycle under the saddle and a forward facing GoPro Hero 5 Session (GoPro, California, USA) was mounted on the handlebars (Figure 1). Each participant was provided with a detailed user guide and was responsible for activating both the MetreBox and GoPro camera at the start of each ride. Both devices recorded constantly. The study research assistant measured the width of the handlebars. The end of the handlebar was deemed to be the widest point on the bicycle. Consistent with prior studies,[18,19] the passing distance was calculated as the distance from the end of the handlebars to the passing motor vehicle.

Procedures

Defining passing event

A passing event was deemed to occur when a motor vehicle passed a cyclist within the recordable range of the MetreBox device. Thus, events in which a cyclist undertook a motor vehicle were excluded. Additionally, events in which a cyclist passed another cyclist were excluded. As per legislation in most Australian jurisdictions,[20] a 'close' passing event was deemed to be an event with a passing distance less than one metre. In Australia, vehicles drive on the left and hence, in this study, we have quantified passing events occurring to the right of the cyclist.

Coding passing events

A manual review of all recorded events was undertaken by two coders who were trained prior to the commencement of coding. This review was firstly used to exclude passing events that were not motor vehicles or events in which a cyclist undertook a motor vehicle. Secondly, characteristics of each event were classified. These characteristics were defined *a priori* using the Cycling Aspects of Austroads Guide[21] as a reference. These were:

- Vehicle type (sedan, taxi, four-wheel drive (4WD), truck, bus, motorcycle, other)
- Location (mid-block, intersection, roundabout)
- On-road marked bicycle lane (present, absent)
- Parked cars on the kerbside (present, absent)

An on-road marked bicycle lane was coded when there was a marked dedicated space for cyclists. A random selection of ten rides were independently coded by two coders and the inter-rater reliability was assessed (see Statistical analyses below).

Map matching, speed zones and road types

To be able to map known locations of passing events to speed zone data, GPS data were aligned to road network maps (OpenStreetMap, OpenStreetMap contributors, 2015. Retrieved from https://planet.openstreetmap.org). This was achieved using a probabilistic map matching approach and implemented in Python using the ST-matching method.[22,23] Speed zone data were obtained from VicRoads' open source shapefile available on data.vic.gov.au.[24]

To quantify the distance that cyclists travelled on-road (and were therefore exposed to motor vehicles), GPS traces were map matched to the OpenStreetMap road and cycle network maps using Python and a modified version of the Open Source Routing Machine (ORSM; http://project-osrm.org/) Map Matching service. OpenStreetMap road classifications were used to classify segments that were on-road (e.g. 'motorway', 'primary', 'residential') and segments that were off-road (e.g. 'cycleway', 'path').

Statistical analyses

Agreement between coders was assessed using percentage of agreement and Cohen's kappa (κ) statistic, [25] with κ scores interpreted as fair (κ=0.21–0.40), moderate (κ=0.41–0.60), substantial (κ=0.61–0.80) and almost perfect (κ=0.81–1.00).[26] Data were summarised using frequencies and percentages for categorical variables and mean and standard deviation (SD) or median and lower (Q1) and upper (Q3) quartiles for continuous variables. A hierarchical linear model was used to investigate the relationship between motor vehicle and infrastructure characteristics and passing distance. Characteristics were modelled as fixed effects. A random intercept and random slope were applied for each rider, with each trip nested within the rider. The correlation type assumed was AR(1), meaning that successive passing distances within the same trip were assumed to be correlated. The hierarchical linear modelling was performed by a statistician (author: J.O.), who was blinded to all variables with the exception of speed zone. As the presence of a marked on-road bicycle lane and the presence of parked cars were highly related, these two variables were modelled as an interaction. To evaluate the addition of other interaction terms, we ran fixed effects models using maximum likelihood to compare various levels of interaction terms (saturated model, 3-way, 2-way and no interaction). Akaike and Bayesian information criterions demonstrated our chosen model fitted the data the best while the likelihood ratio test also preferred this model after adjusting for multiple testing. Speed zone was missing in 7.3% (n=1350) of passing events and vehicle type was missing in 0.01% (n=23) of passing events and these events were excluded from the hierarchical linear model. Additional hierarchical linear models were used to quantify the average distance participants travelled per trip, the average number of passing events per 10 km travelled and the average number of passing events less than 100cm per 10 km travelled. Data are reported as averages with 95% confidence intervals (CI).

Two sensitivity analyses were conducted. Firstly, the impact of excluding cases with missing speed zone (n=1350) was evaluated. A chi-square goodness of fit test was used to compare the average passing distance when the model included and excluded speed zone (observations with missing speed zone were excluded from both models). Secondly, we investigated the relationship between motor vehicle and infrastructure characteristics and passing distance relative to legislated passing distances in other regions of Australia. Legalisation or trials of minimum passing distances have been legislated in other regions of Australia and stipulate that drivers must provide a passing distance of at least 1 metre when the speed limit is 60 km/h or less, and 1.5 metres when the speed limit is more than 60 km/h.[27] Therefore, in this sensitivity analysis, we centred passing distance at 1 metre in speed zones of 60 km/h or less and 1.5 metres in speed zones of greater than 60 km/h. Negative and positive values of passing distance were therefore relative to these recommended passing distances. A chi-square goodness of fit test was used to compare this model with the main model with passing distance as an absolute value.

Data analysis was performed using Stata (Version 14.2, StataCorp, College Station, TX) and SAS (Version 9.4, SAS Institute Inc., Cary, NC, USA). The importance of a variable was assessed by its p-value and effect size.

RESULTS

Sixty-three participants consented to participate. Of these, complete data were available for 60 participants (two participants were not able to activate the device and one participant did not ride during the data collection period). The participants with complete data had a median age of 39.3 years (Q1: 32.0 years, Q3: 48.5 years) and 75% (n=45) were male. A total of 422 trips were recorded, with a mean of 7 trips per participant (SD: 3.14). Participants rode a total of 5,302 km, of which 4,831 km (91%) was classified as on-road. The average trip distance was 12.6 km (95% CI: 11.9, 13.3) of which the average distance ridden on-road per trip was 11.5 km (95% CI: 10.9, 12.1).

A total of 18,527 passing events were recorded with a median passing distance of 173 cm (Q1: 137cm, Q3: 224cm; range: 24cm – 330cm). Participants recorded an average of 28.0 passing events per 10 km travelled (95% CI: 25.8, 30.4). Of these, 0.7% were less than 60cm, 1.4% between 60 and 79cm and 3.8% between 80 and 99cm (Table 1). Overall, 1,085 (5.9%) passing events were less than 100cm. Participants recorded an average of 1.7 passing events less than 100cm per 10 km travelled

(95% CI: 1.5, 1.9). For passing events in speed zones of 60 km/h or less (n=16,274; 95%), the proportion of passing events less than 100cm was 5.9% (n=952). For passing events in speed zones of greater than 60 km/h (n=903; 5%), the proportion of passing events less than 150cm was 32% (n=293). Between-subject variation was noted for mean passing distances and for the proportion of passing events less than 100cm. Mean passing distances varied between cyclists from 147cm to 230cm (Figure 2). The mean proportion of passing events less than 100cm varied between cyclists from 0.9% to 29.9% (Figure 3).

Most passing events involved sedans (70.4%) or 4WDs (17.2%), occurred mid-block (89.8%), occurred in the absence of a marked on-road bicycle lane (57.6%), in the absence of parked cars on the kerbside (83.0%) and in speed zones of 50 km/h (22.6%) or 60 km/h (61.0%) (Table 1). Figures 5-8 provide unadjusted differences in passing distances for each characteristic. The proportion of passing events <100cm was greater when the cyclist was riding in a marked on-road bicycle lane relative to a road without a bike lane (6.8% vs 5.1%; P<0.001).

Results from the hierarchical linear model are shown in Table 2. Relative to sedans, 4WDs had a mean lower passing distance of 15cm (Q1: 12cm, Q3: 17cm) and buses had a reduced mean passing distance of 28cm (Q1: 16cm, Q3: 40cm). Relative to passing events that occurred on roads without a marked bicycle lane and without parked cars, passing events on roads with a bike lane with no parked cars had a reduced mean passing distance of 27cm (Q1: 25cm, Q3: 29cm), and passing events on roads with a bike lane and parked cars had a reduced mean passing distance of 40cm (Q1: 37cm, Q3: 43cm) (Figure 9). Passing events that occurred on roads without a marked bicycle lane and without parked cars had a lower estimated proportion of passing events <100cm (5%) compared to passing events that occurred on roads with a bike lane and parked cars (9%). There were no notable differences between locations or speed zones.

Sensitivity analyses

In a sensitivity analysis comparing the primary model with a model that included all variables with the exception of speed zone (and included all cases), there were no significant differences in model coefficients (χ^2=1.302; df=12; P>0.99). Similarly, in a sensitivity analysis comparing the primary model with a model with passing distance centred around 1 metre in speed zones of 60 km/h or less and 1.5 metres in speed zones of greater than 60 km/h, there were no significant differences in model coefficients (χ^2=0.046; df=18; P>0.99).

Inter-rater reliability

There were 558 passing events that were independently coded by two coders. 513 (92%) were coded by both coders and 45 (8%) were coded by only one coder. There was almost perfect agreement for location (κ = 0.88; 95% CI: 0.82, 0.94), bike lane (κ = 0.82; 95% CI: 0.77, 0.87) and the presence of parked cars (κ = 0.84; 95% CI: 0.77, 0.90), and substantial agreement for vehicle type (κ = 0.69; 95% CI: 0.62, 0.76). The most frequent disagreement for vehicle type was sedan and 4WD (percentage agreement = 42%).

DISCUSSION

We quantified the distance that motor vehicles provide when passing cyclists and investigated the impact of motor vehicle and road infrastructure characteristics on passing distance. In a sample of 18,527 passing events, approximately one in every 17 passing events was a ‘close’ pass (<100cm). In higher speed zones, over 60kph, one in every three passing events was a ‘close’ pass (<150m). We noted important links between motor vehicle types and infrastructure characteristics, and passing distance. These data demonstrate that road infrastructure is associated with passing distance and can be used to inform the selection and design of cycling-related infrastructure.

Previous studies that have quantified the passing distance that motor vehicles provide to cyclists have commonly used an instrumented bicycle on a set route,[10-13] or have used a limited number of fixed traffic cameras to estimate passing distance.[15] To our knowledge, our study is the first study to use technology mounted on cyclists' own bicycles to quantify passing distance with cyclists riding on self-selected routes. Furthermore, the number of passing events in our study (n=18,527) is substantially larger than that previously reported (e.g. n=145,[11] n=1380,[12] n=1846[15]; see Table 3). In the current study, we observed a mean passing distance of 173cm. This is slightly lower than data from another Australian state, Queensland, in which a mean passing distance of 186cm was reported,[15] and 6.4 ft (195cm) reported in Wisconsin, United States.[13] In contrast to our study, both of these prior studies were conducted in settings with legislated bicycle passing distance rules.

Data on the effectiveness of marked on-road bicycle lanes in reducing crashes are limited. Some studies have suggested that bicycle lanes offer reduced crash risk,[28-30] while others have suggested that they offer no benefit.[31] The findings of the current study indicate that passing distance was reduced when the cyclist was riding in a marked on-road bicycle lane, and this is supported by a study from the United Kingdom that reported a reduced passing distance of between 7cm and 18cm.[10] In addition, we observed a greater rate of close passing events when the cyclist was riding on a road with a marked bicycle lane (6.8% vs 5.1%). It has been suggested that this is a result of driver perceptions. Specifically, in situations where the cyclist is in the same lane as the motorist, the driver is required to perform an overtaking manoeuvre (i.e. change lanes to pass). Whereas, in situations where the cyclist is in a dedicated marked bicycle lane, the motorist has a clear lane ahead and is not required to perform an overtaking manoeuvre.[10] As a result, there is less of a conscious requirement for drivers to provide additional passing distance.

Road lane width has also been identified as an important factor with increased lane widths having been shown to facilitate greater passing distances.[18] Furthermore, lane widths may also explain some of the variation in passing distance we observed between vehicle types. For example, the reduced passing distance observed with buses, relative to sedans, may be explained by the greater width of buses. We were unable to obtain accurate lane width data across the entire road network of metropolitan Melbourne and thus this is a factor we were unable to control for. Similarly, the number of lanes of traffic in the direction of travel for the cyclist may also influence driver overtaking manoeuvres and hence passing distance. However, these data were also unavailable.

The reduction in passing distance when the cyclist was riding in a marked bicycle lane was further exacerbated when parked cars were present. The reduced passing distance in the presence of parked cars may be explained by cyclists' choice of lane position, in that they may be electing to move outside of the 'dooring' zone.[32] It has also been shown that cyclist crash odds are higher on roads with parked cars relative to roads without parked cars.[30] We noted substantial between-cyclist variation in mean passing distances and the proportion of close passing events. This is suggestive of an influence of rider behaviour or route selection on passing distance. However, further work is required to quantify this.

We observed no notable differences in passing distances between speed zones, suggesting that drivers do not adapt the clearance provided to cyclists with speed. In other regions of Australia (with the exception of our region of Victoria), legalisation or trials of minimum passing distances have been legislated and stipulate that drivers must provide a passing distance of at least 1 metre when the speed limit is 60 km/h or less, and 1.5 metres when the speed limit is more than 60 km/h. In line with our finding that passing distance did not differ between speed zones, and consistent with Debnath *et al.* (2018),[15] we observed a higher proportion of passing events in which the passing distance was less than these suggested boundaries in speed zones of greater than 60 km/h. Given that passing vehicle speed is known to be a major concern for cyclists,[33] speed-based minimum passing distance regulations are justified, and our results demonstrate the need to increase education for drivers to provide greater passing distance at higher vehicle speeds.

Overall, these findings have important implications for the selection and design of cycling-related infrastructure. Specifically, these findings suggest that marked on-road bicycle lanes, particularly alongside parked cars, are not the optimal solution for maximising motor vehicle passing distance.

This begs the question: is a single stripe of white paint enough to protect cyclists? That is not to suggest that we should not provide on-road marked bicycle lanes. Rather, the focus of on-road cycling infrastructure needs to be on providing infrastructure that separates cyclists from motor vehicles by a physical barrier. If this is not possible, then at a minimum, buffer zones should be provided between the edge of the cycle lane and motor vehicle traffic lanes, and, if necessary, between the bicycle lane and parked cars.

The proportion of close passing events recorded in this study reflects one close passing event for every 17 motor vehicles that pass. Given that close passing events are a key contributor to reduced perceived safety in cyclists,[7] it is clear that efforts to reduce close passing events will improve the experience of people cycling on our roads with the aim of increasing cycling participation.

The strengths of this study include the use of on-bike technology that enabled the quantification of passing distance while cyclists were using their own bicycles and as part of normal riding. The manual review of all recorded events, while time-consuming, provided a robust and detailed approach to classifying motor vehicle and road infrastructure characteristics, and for confirming motor vehicle passing events (and excluding situations in which a cyclist undertook a motor vehicle). Although some variation was noted between coders. Furthermore, data were collected on cyclists riding in metropolitan Melbourne and therefore these data may not be reflective of cyclists in outer suburbs or regional areas. Additionally, given the frequency of data collection from the ultrasound sensor, it is likely that the sensor detected the motor vehicle body, rather than the side mirrors, and therefore passing distances are likely to be conservative estimates. Additionally, the proportion of passing events less than 100cm is related to the maximal distance that the sensor can read. For example, if the maximal recordable distance is restricted to 300cm, 250cm or 200cm, the proportion of close passing events increases to 6.1%, 7.0% and 8.9%, respectively. A small amount of data were missing for speed zone, which was an artefact of lost GPS signals. However, sensitivity analyses revealed that this did not appreciably impact on model estimates. Further, and as noted above, data were not available on road lane widths, bicycle lane widths or number of lanes and hence we could not control for these factors. Additionally, there were a small number of passing events that could not be coded due to inadequate ambient lighting and these events were excluded from analyses. There is also a need to understand how cyclists' subjective experiences align with quantified passing distances.

CONCLUSION

From a large sample of events in which a motor vehicle passed a cyclist, one in every 17 passing events was a close passing event (<100cm) and in higher speed zones (over 60kph), one in every three was a close passing event (<150cm). We identified that road infrastructure had a substantial influence on the distance that motor vehicles provide when passing cyclists. Specifically, we demonstrated that on-road bicycle lanes reduced passing distance. These data can be used to inform the selection and design of cycling-related infrastructure that actually provides a safety benefit for cyclists.

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TABLES

Table 1: Number of passing events by passing distance, motor vehicle or infrastructure characteristic.

Characteristic		**N (%)**	**Passing distance Mean (SD)**
Passing distance			
	0-59 cm	124 (0.7%)	
	60-79 cm	254 (1.4%)	
	80-99 cm	707 (3.8%)	
	100-119 cm	1528 (8.2%)	
	120-149 cm	3652 (19.7%)	
	150-199 cm	5861 (31.6%)	
	200-249 cm	3305 (17.8%)	
	250 cm and greater	3096 (16.7%)	
Motor vehicle type			
	Sedan	13031 (70.4%)	185 (61)
	Taxi	357 (1.9%)	166 (60)
	4WD	3173 (17.1%)	177 (59)
	Truck	379 (2.0%)	185 (69)
	Bus	86 (0.5%)	161 (71)
	Other	1478 (8.0%)	176 (60)
Location			
	Intersection related	1884 (10.2%)	182 (65)
	Mid-block	16631 (89.8%)	183 (60)
	Roundabout	12 (0.1%)	167 (84)
Presence of a marked on-road bicycle lane			
	No	10674 (57.6%)	196 (65)
	Yes	7853 (42.4%)	164 (49)
Presence of parked cars on the kerbside			
	No	15381 (83.0%)	188 (62)
	Yes	3146 (17.0%)	158 (49)
Speed zone[a]			
	40 km/h or less	1931 (11.2%)	168 (56)
	50 km/h	3873 (22.5%)	170 (57)
	60 km/h	10470 (61.0%)	190 (62)
	70 km/h	345 (2.0%)	189 (62)
	80 km/h	539 (3.1%)	182 (58)
	100 km/h	19 (0.1%)	154 (51)

Note: Missing data: a) n=1,350 (7.3%)

Table 2: Results of the hierarchical linear model investigating the relationship between motor vehicle and infrastructure characteristics, and passing distance (N=17,156). Values represent the difference of least square means.

Characteristic		**Difference in passing distance (Q1, Q3) (cm)**
Motor vehicle type		
	Sedan	*Reference*
	Taxi	- 8 (-14, -2)
	4WD	-15 (-17, -12)
	Truck	-8 (-14, -2)
	Bus	-28 (-40, -16)
	Other	-12 (-15, -9)
Location		
	Intersection related	*Reference*
	Mid-block	9 (6, 11)
Interaction of bicycle lane and parked cars		
	No bike lane, no parked cars	*Reference*
	Bike lane, no parked cars	-27 (-29, -25)
	No bike lane + parked cars	-30 (-34, -27)
	Bike lane + parked cars	-40 (-43, -37)
Speed zone		
	40 km/h or less	-8 (-11, -5)
	50 km/h	-5 (-8, -3)
	60 km/h	*Reference*
	70 km/h	-7 (-14, -1)
	80 km/h	-6 (-12, 0)
	100 km/h	-18 (-43, 7)

Table 3: Summary of prior studies that quantified the lateral passing distance that motor vehicles provide when passing cyclists.

Study	**Number of passing events**	**Number of riders**	**Number of trips**	**Details**
Current study	18,527	60	422	Device installed on cyclist's own bicycle
Other studies				
Walker *et al.* (2014)[19]	5,690	1	67	Instrumented bicycle
Feng *et al.* (2018)[17]	4,789	Unknown	Unknown	Existing motor vehicle naturalistic driving study
Llorca *et al.* (2017)[34]	2,928	1	7	Instrumented bicycle
Walker (2007)[14]	2,355	1	Unknown	Instrumented bicycle
Debnath *et al.* (2018)[15]	1,846	Unknown	Unknown	Video observations at 15 sites
Chuang *et al.* (2013)[12]	1,380	34	34	Instrumented bicycle
Chapman & Noyce (2012)[13]	1,151	Unknown	Unknown	Instrumented bicycle
Parkin & Meyers (2010)[10]	843	Unknown	Unknown	Instrumented bicycle
Love *et al.* (2012)[18]	586	5	34	Video camera mounted on cyclists' own bicycle
Dozza *et al.* (2016)[11]	145	2	Unknown	Instrumented bicycle
Kovaceva *et al.* (2018)[16]	83	Unknown	Unknown	Existing motor vehicle naturalistic driving study

FIGURES

Figure 1: The MetreBox device (A) and the device installed on a bicycle with GoPro camera mounted on handlebars (B).

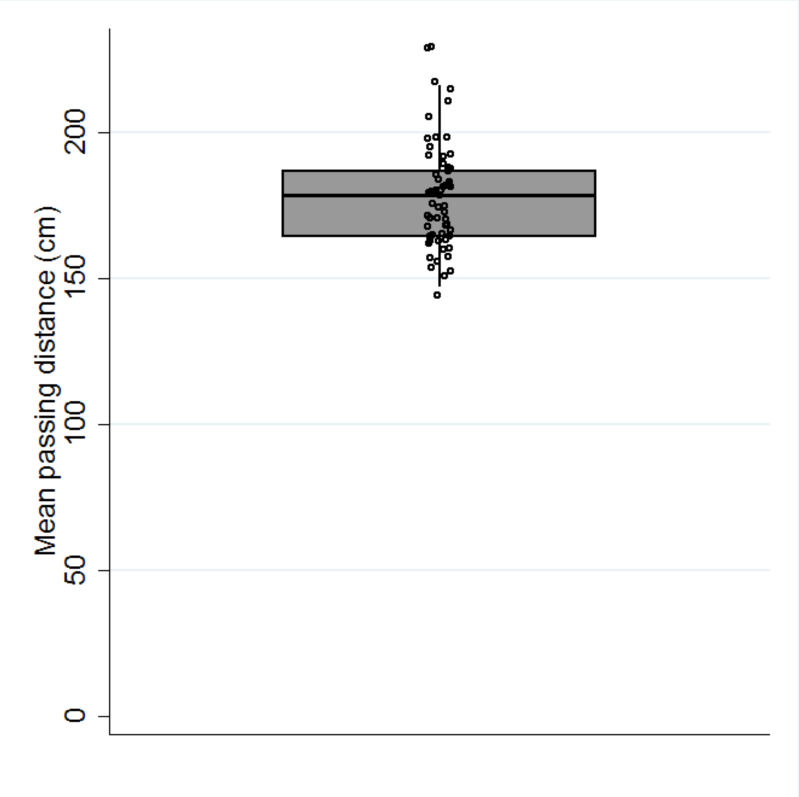


Figure 2: Mean passing distance per participant (markers reflect individual participants).

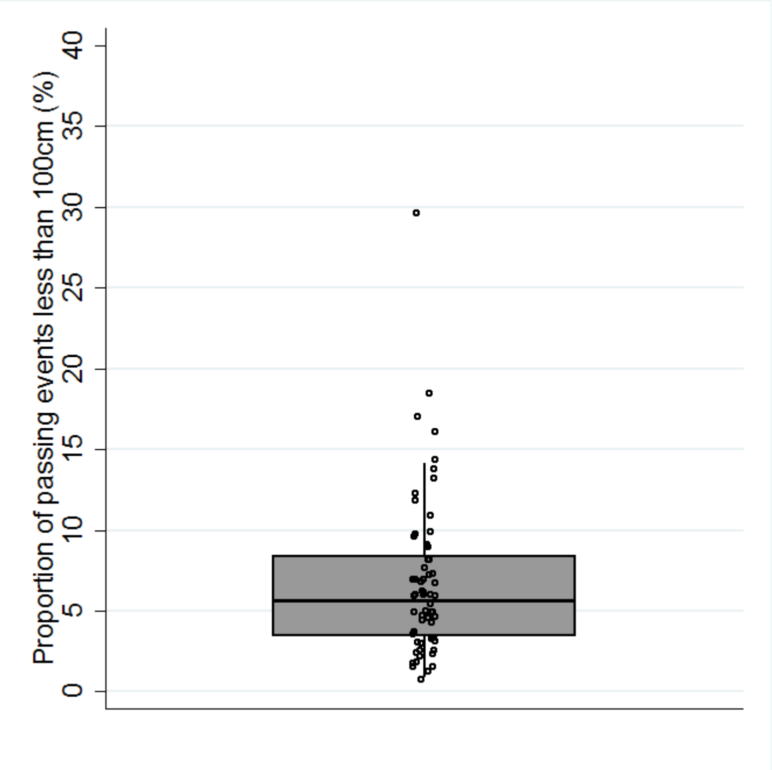


Figure 3: Mean proportion of passing events less than 100cm per participant (markers reflect individual participants).

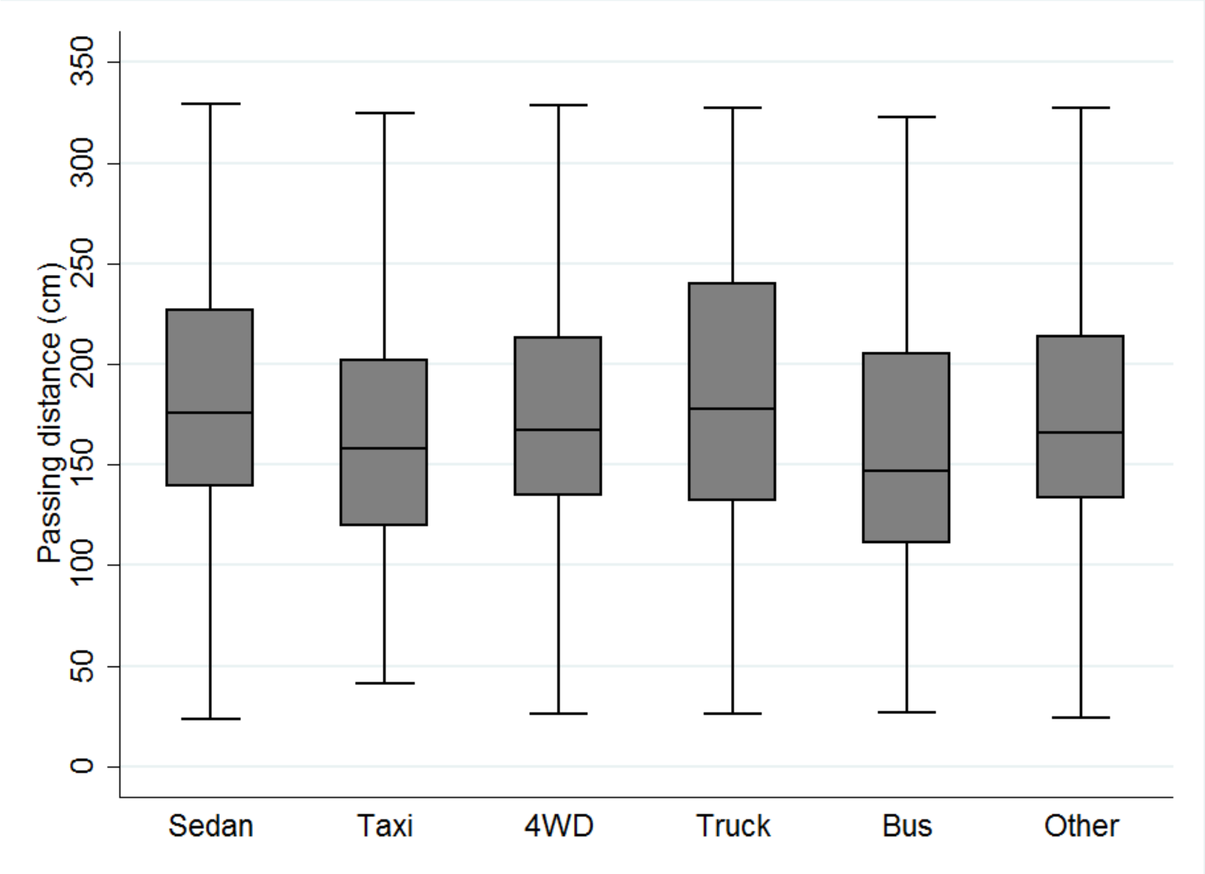


Figure 4: Mean passing distance by motor vehicle type.

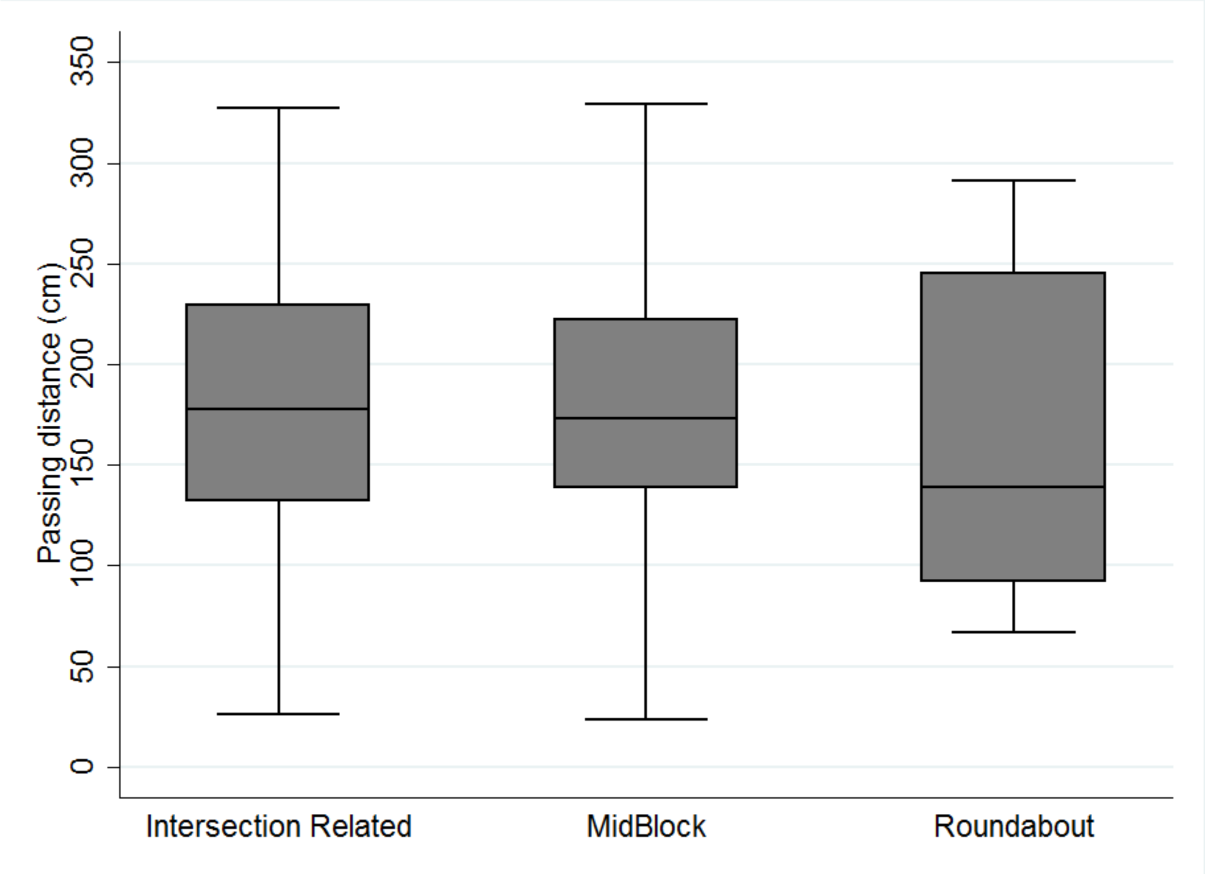


Figure 5: Mean passing distance by location.

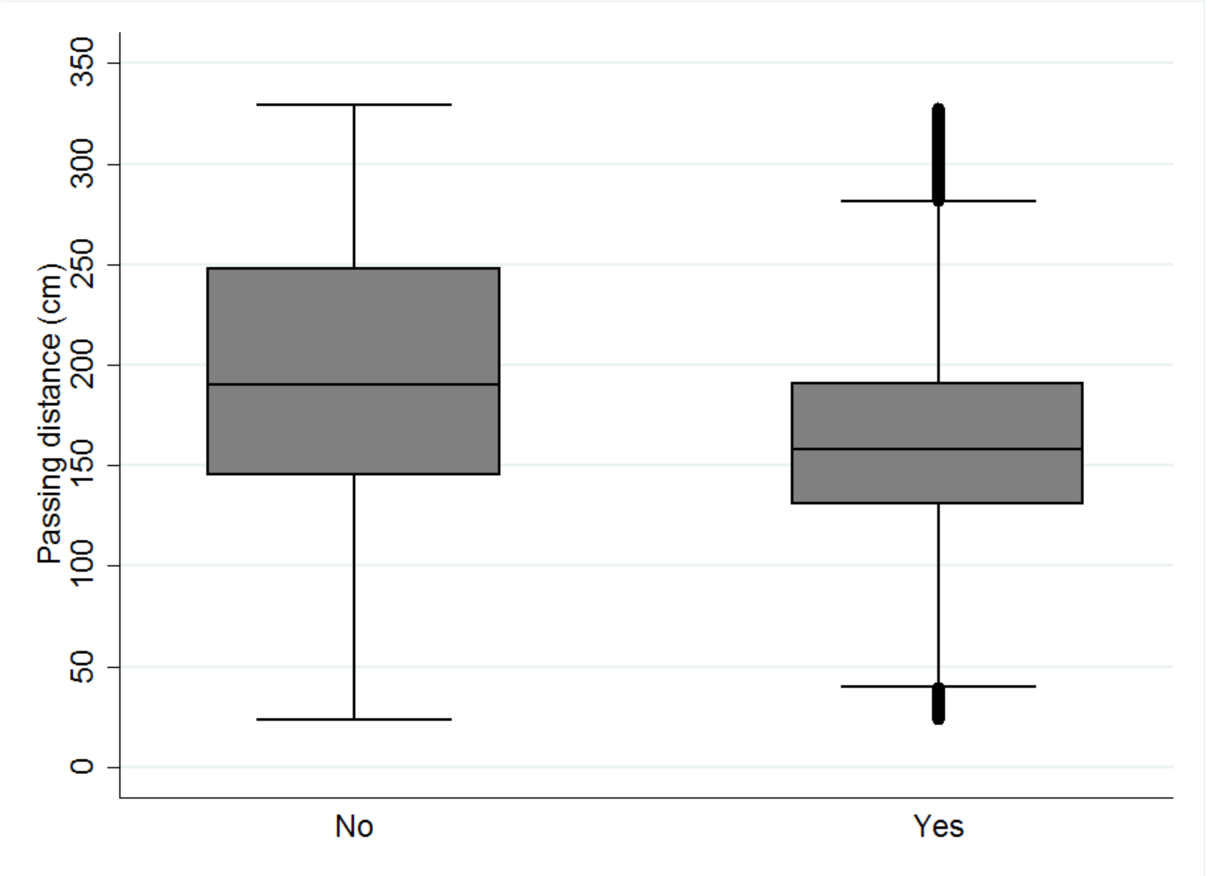


Figure 6: Mean passing distance by presence/absence of a marked on-road bicycle lane.

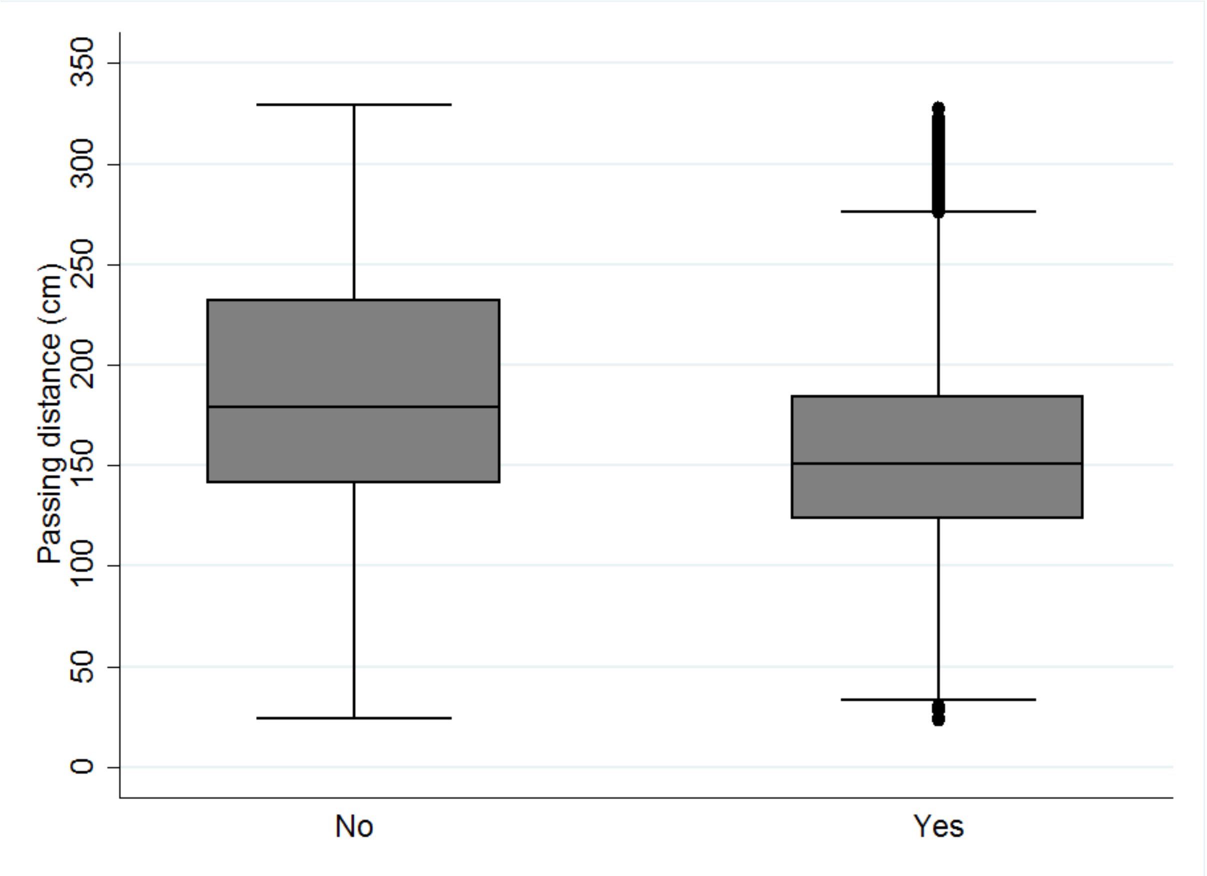


Figure 7: Mean passing distance by the presence/absence of parked cars on the kerbside.

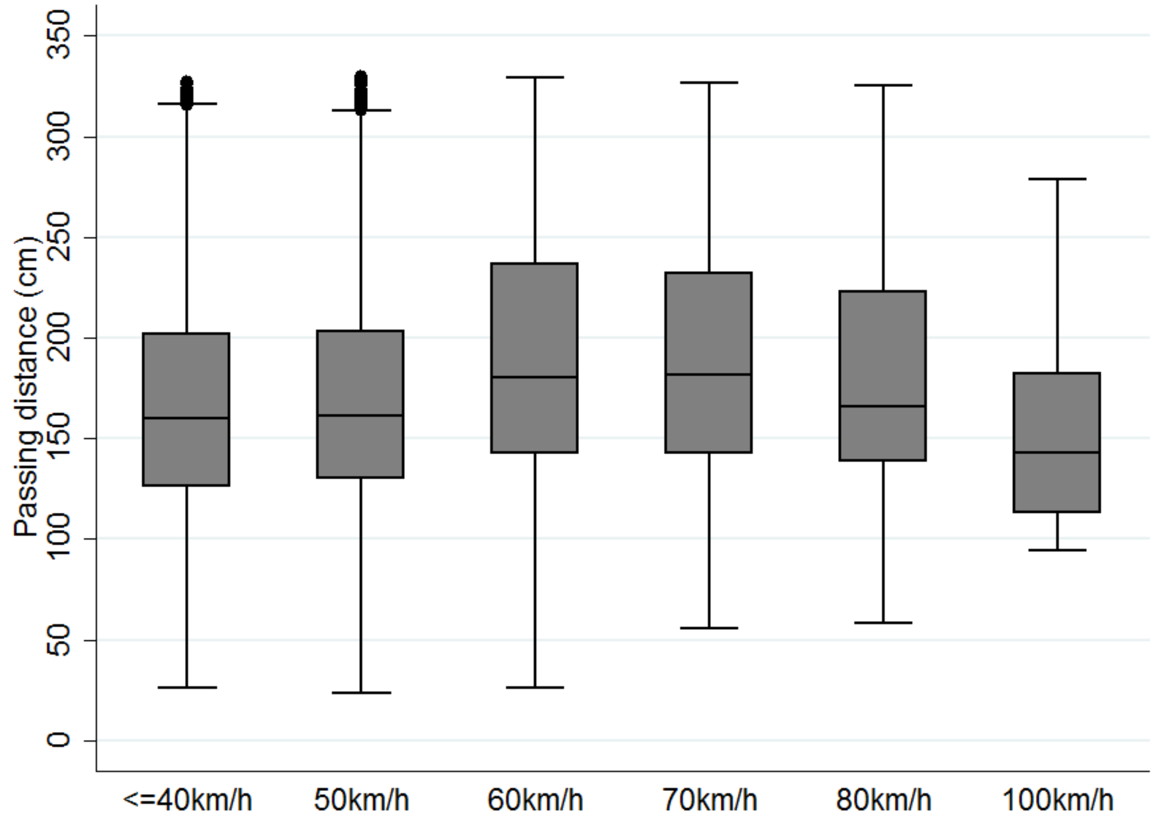
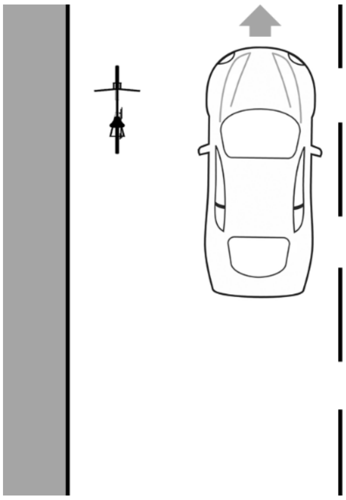
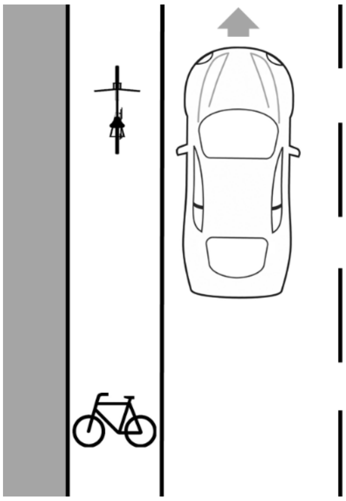


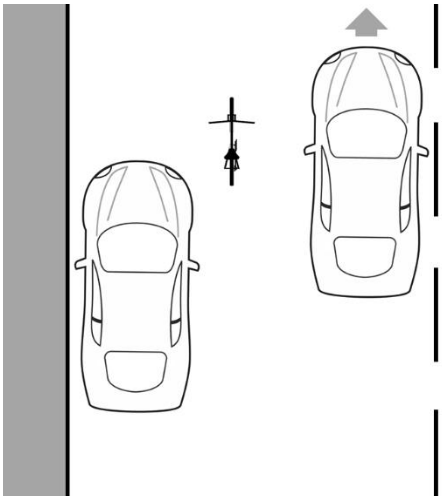
Figure 8: Mean passing distance by speed zone.



A: Reference



B: 27cm less



C: 30cm less

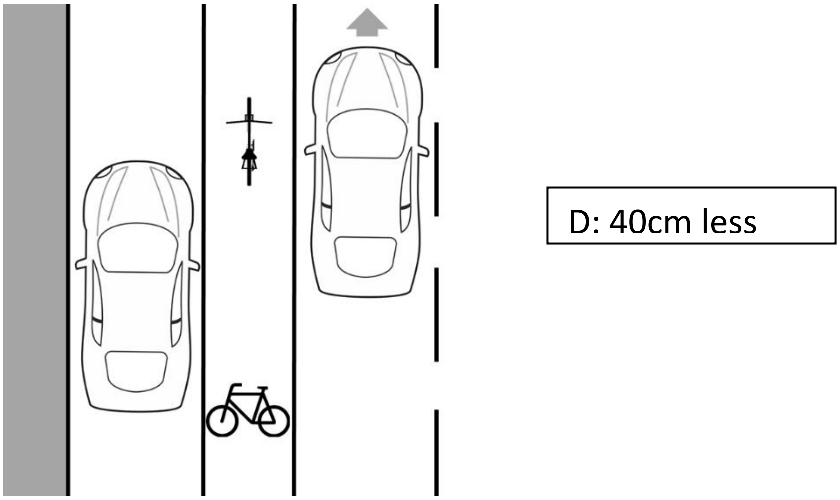


Figure 9: Results of hierarchical linear model for the interaction of bicycle lane and parked car on passing distance. Situation A reflects a scenario of no bike lane and no parked cars. Situation B reflects a scenario of a bike lane with no parked cars. Situation C reflects a scenario of no bike lane with parked cars. Situation D reflects a scenario of a bike lane with parked cars.