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Bicyclist's perceived level of comfort in dense urban environments: How do ambient traffic, engineering treatments, and bicyclist characteristics relate?

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ABSTRACT

In dense urban environments, truck loading zones introduce multimodal conflicts that could decrease the bicyclist's perceived level of comfort (PLOC), potentially reducing bicycle mode share. This study investigated the PLOC of bicyclists near urban loading zones, according to different levels of ambient traffic (low traffic volume, high traffic volume, and truck traffic), bicycle lane pavement markings (white lane markings, solid green, and dashed green), and traffic signs (no sign or warning sign). An online survey was designed and randomly distributed to 10,000 potential participants. A total of 342 participants successfully completed the survey. Repeated-measures ANOVA results indicated that when bicycling on a conventionally striped bike lane, truck traffic had the most significant effect on bicyclist PLOC, decreasing it by more than 42%. Pavement markings were more effective than traffic signs at improving bicyclist PLOC, but no difference was observed between solid and dashed green lane markings. Finally, the results of cluster analysis indicated that the effect of gender and experience on bicyclist PLOC varied with different levels of traffic and engineering treatments. Women were more affected than men by the presence of a truck in the adjacent lane but they were also more prone to a considerable increase in PLOC values due to the implementation of engineering treatments. Findings of this study could inform future policies regarding transportation infrastructure design to support safer and more comfortable bicycling in dense urban environments.

1. Introduction

There are growing concerns over the effects of motor vehicle use on the environment, neighborhood livability, safety, and health. These concerns have contributed to a paradigm shift from motorized to non-motorized modes of travel in transportation infrastructure planning, design, construction, operations, and maintenance, especially in dense urban areas. This change, in turn, has increased the popularity of bicycling. According to the U.S. Census Bureau, the number of individuals who commuted to work by bicycle in the United States grew by 50% between 2000 and 2012 (McKenzie, 2014). As a mode of active transportation, the bicycle could play a pivotal role in sustainable communities (Balsas, 2003; Rowangould & Tayarani, 2016). Traffic congestion in urban areas has led many cities to encourage bicycling as a functional alternative to driving. Bicycling is less infrastructure-intensive than public transportation and has a much longer range than walking. Many U.S. cities have plans to increase their bicycle mode share. For example, Portland, Oregon, adopted a bicycle plan that aims to achieve a 25% bicycle mode share by 2030 (PBOT, 2010).

As bicycling in urban areas grows in popularity, conflicts between bicycles and other transportation modes have become increasingly problematic. Despite the decrease in total number of motor-vehicle traffic fatalities, the proportion of all bicyclist fatalities among all fatalities increased from 1.47% in 2003 (629/42,884 bicyclist/total fatalities) to 2.33% in 2015 (818/32,166 bicyclist/total fatalities) (FARS, 2017). More specifically, bicycle conflicts with freight vehicles in dense urban areas often result in severe consequences. Large trucks are the only vehicle classification to be overrepresented in bicyclist fatalities in recent years. For example, large trucks were involved in 6.48% of bicyclist fatalities in the United States in 2015, despite comprising only 3.98% of registered vehicles (NHTSA 2017a; NHTSA 2017b).

In dense urban environments, commercial parking and loading zones are potentially high-risk areas for bicycle-truck conflicts (Conway, Thuillier, Dornhelm, & Lownes, 2013), which could decrease bicyclists' perceived level of comfort (PLOC) and negatively influence bicyclist behavior, leading to severe consequences (Duthie, Brady, Mills, & Machemehl, 2010; Teschke et al., 2012). Low PLOC while traveling near motorists is a significant factor in preventing people from bicycling (Sanders, 2013). This is a hindrance in promoting sustainable

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cities through active transportation.

Several types of engineering treatments, such as colored pavement markings and warning signs, can be applied to roadways to improve bicyclist safety in conflict areas. Colored pavement within a bicycle lane increases visibility of the facility, identifies potential conflict areas, and reinforces bicyclist priority in these areas. This treatment is commonly applied to conflict areas at intersections, driveways, and along non-standard or enhanced facilities, such as cycle tracks (NACTO, 2011). Warning signs can be used to inform road users of a potential hazard that might not be readily apparent. The *Manual on Uniform Traffic Control Devices* (FHWA, 2009) defines three types of signs for bicycle facilities: regulatory signs, warning signs, and guide signs. However, no endorsed sign directly addresses bicycle-truck interactions in urban loading zones. Furthermore, although these engineering treatments are designed and implemented to increase safety, it is unclear whether treatments in conjunction with ambient traffic conditions influence the bicyclist's perceived safety and comfort near loading zones in urban areas.

With the aim of promoting bicycling in urban areas, this study investigated the PLOC of bicyclists under different conditions of ambient traffic and engineering treatments, and considered gender and experience related differences in bicyclist PLOC. More specifically, this study evaluated whether the presence of engineering treatments, such as colored bike lanes or warning signs in conflict areas, influence bicyclist PLOC under various traffic conditions, and whether this influence is affected by the bicyclist's gender and experience.

2. Literature review

Previous research considered the PLOC of bicyclists on various roadway facilities. Traffic volume has been demonstrated to have a significant influence on bicyclist PLOC. A survey of 1402 current and potential bicyclists in Vancouver, Canada, indicated that one of the greatest motivators of an individual's decision to bicycle was whether a route was separated from traffic. Most respondents were more likely to ride on facilities that had low traffic volumes or separated bicyclists from vehicular traffic (Winters, Davidson, Kao, & Teschke, 2011). Other research considered specific types of treatments that help improve perceived levels of comfort and safety. A recent study investigated the comfort level of bicyclists in various types of buffered bike lanes, using generic diagrams of facilities. Respondents rated protected bicycle facilities with physical buffers as offering greater PLOC than standard bike lanes (McNeil, Monsere, & Dill, 2015). Monsere et al. (2014), found similar results, noting that physical barriers provided more comfort for bicyclists than painted buffers.

The perception of safety influences the decision to bicycle and the frequency of bicycling. One comprehensive study conducted in the Bay Area demonstrated that the perceived risk greatly influences the attractiveness of a facility, particularly for infrequent and potential bicyclists (Sanders, 2013). Improving the perceived safety of a bicycling infrastructure is an important condition for increasing levels of bicycling (Dill & Mcneil, 2013). In a survey of 1707 cyclists in Montreal, Canada, the perception of safety was one of the most influential factors in determining the frequency of cycling, even for experienced cyclists (Damant–Sirois & El–Geneidy, 2015).

Two decades ago, transportation planning goals were heavily mobility-based, but there has been substantial advancement since the early 2000 s in acknowledging social equity issues as being of critical importance as well (Manaugh, Badami, & El-Geneidy, 2015). Bicycling has long been promoted as a form of social equity which also contributes to sustainability in urban environments. Social equity in transportation necessitates that people with diverse backgrounds, different demographics, and various capabilities to be considered in the planning and design process. The data shows that today in the United States, for every 3 male bicyclists, there is only 1 female bicyclist who commutes to work (McKenzie, 2014). This problem is closely tied to the gender-related perception of safety and comfort regarding bicycling in dense urban environments. The role of gender in bicycling behavior has been widely studied in recent literature (e.g., McNeil et al., 2015; Monsere, Dill, McNeil, & Clifton, 2014). Women's perceptions of safety and comfort are critical elements in their tendency to bicycle (Tilahun, Levinson, & Krizek, 2007). One study analyzed three different surveys in Minnesota with a focus on safety and cycling infrastructure preferences. Women were more likely to report a lack of bicycle paths as a reason for not feeling "very safe" when bicycling. Women were more likely to prefer safer forms of bicycling infrastructure and were willing to accept longer travel times than men to access a preferred facility (Krizek, Johnson, & Tilahun, 2005). Another survey of six small cities in the western United States evaluated factors influencing the decision to bicycle. Using multivariate analysis, the study found that comfort level was one of the most important factors for women choosing to bicycle. Women were generally comfortable on off-street paths and were more concerned than men about safety (Emond, Tang, & Handy, 2009).

With regards to the interaction of bicycles and trucks in urban loading zones, very little previous research exists. Conway et al. (2013) collected observations at loading zones in Manhattan, New York City, and found that about 14% of commercial vehicles conflicted with a bicycle in dense urban areas. Additionally, they found a correlation between bicycle lane configurations and conflict frequency. In another study, the same research group found that more than half of bicycle collisions in New York City occurred on truck routes, which make up only 19% of the on-street bicycle network. Commercial vehicle involvement in bicycle collisions was highly related to land use type and freight demand (Conway et al., 2016).

Moreover, whereas numerous studies have evaluated bicyclist PLOC on roadway facilities, comparatively little research has looked specifically at PLOC near urban loading zones. Sanders (2013) reported that bicyclists preferred route alternatives that did not include bicycle lanes next to on-street parking, presumably because of conflicts with vehicles (e.g., attempting to enter/exit the parking lane, opening the door into the bicycle lane, etc.). Among surveyed bicyclists across eight facilities in the United States, 25% stated that delivery vehicles loading or unloading are often encountered in a protected bike lane. Moreover, 36% of surveyed bicyclists stated that vehicle loading/unloading is a major problem (McNeil et al., 2015). This negative perception of the interaction between delivery vehicles and bicyclists in an urban environment has yet to be considered through the lens of PLOC. Therefore, this research attempted to quantify the factors that influence bicyclist PLOC near urban loading zones.

3. Method

3.1. Study design and survey

Scenarios with different levels of ambient traffic and engineering treatments were created to represent bicycling near a loading zone in a dense urban environment. Three levels of ambient traffic were considered: 1) low traffic volumes, 2) high traffic volumes, and 3) truck traffic in the adjacent lane. For pavement marking levels, recommendations from the National Association of City Transportation Officials *Urban Bikeway Design Guide* (NACTO, 2011) were considered. Three levels of bike lane pavement markings were used: 1) white lane markings with no supplemental pavement color (called white lane markings hereafter), 2) white lane markings with solid green pavement applied on conflict area (called solid green hereafter), and 3) white lane markings with dashed green pavement applied on conflict area (called dashed green hereafter). Finally, two levels of traffic signs were considered: 1) no sign and 2) sign warning bicyclists of a potential truck conflict on the road. These independent variables (factors) and levels resulted in a study with a 3 × 3 × 2factorial design. Google Sketchup 2017 software was used to create three-dimensionally rendered images illustrating the factorial design. The roadway cross-section included

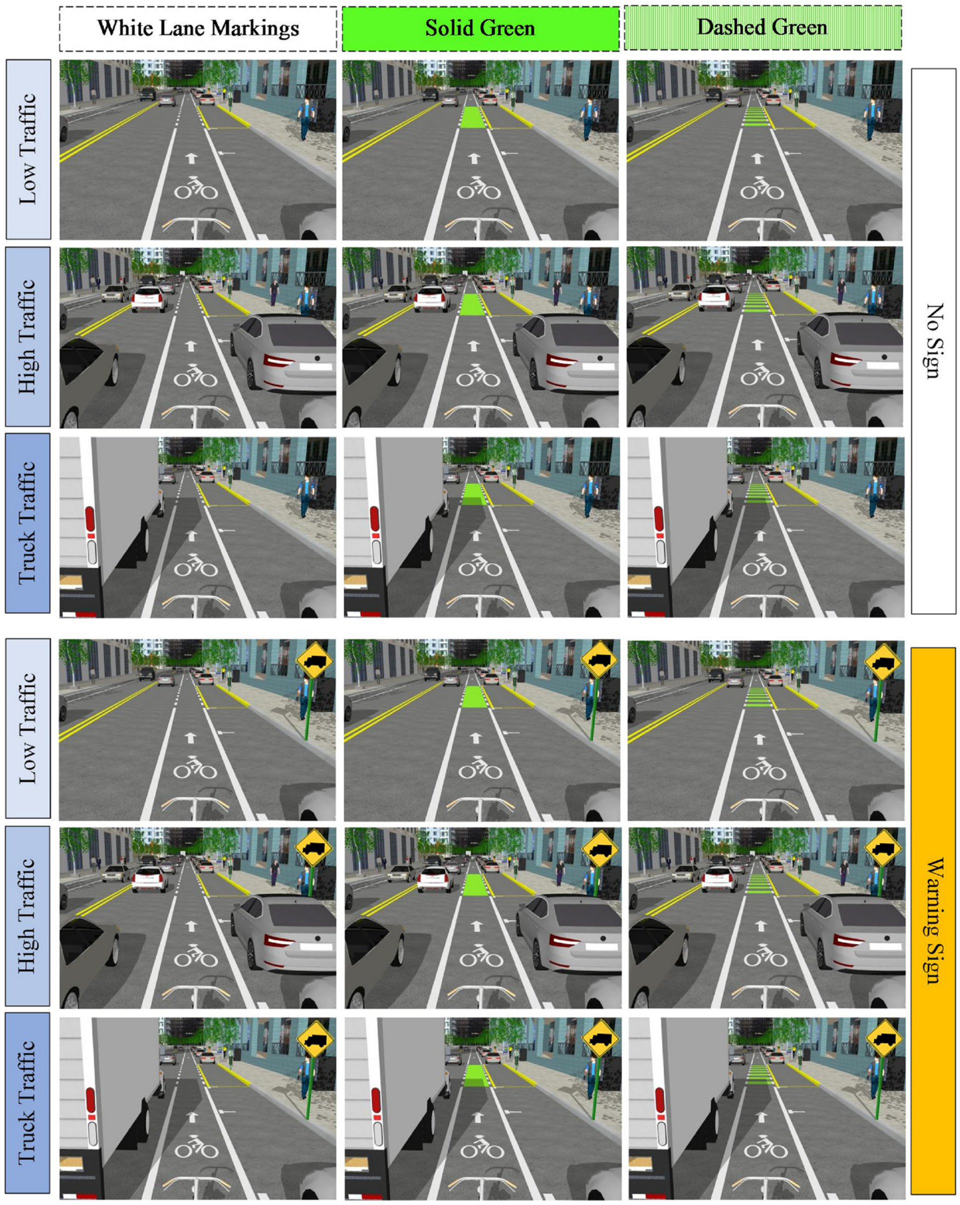

Fig. 1. Different Levels of Independent Variables (Factors).

two 12-ft travel lanes with 6-ft bicycle lanes in each direction. An 8-ft parking lane interrupted by an on-street loading zone was created in one direction to account for bicycle-truck interactions. Fig. 1 shows the different levels of independent variables considered in the survey.

Online surveys have been widely adopted to study road users' behavior (e.g., Neill, Hurwitz, & Olsen, 2016; McNeil et al., 2015; Sanders, 2013; Hassan & Abdel-Aty, 2011). In this study, Qualtrics was used to develop an online survey. Recommendations from literature were considered to validate the survey design and reduce total survey errors (Dillman, Smyth, & Christian, 2009). Survey questions were designed and revised through an iterative process. Initially, the developed survey was beta tested with selected students from the Transportation Group at Oregon State University (OSU) and was revised accordingly. The survey was further modified based on feedback from faculty in the School of Psychology and School of Statistics at OSU. The final survey consisted of two sections. The first section included demographic questions including items related to age and gender and questions about the frequency and primary purpose of bicycling trips. Notably, participants were asked to rate their level of experience as a bicyclist on a 10-point rating scale, from very inexperienced (0) to very experienced (10). The second section of the survey randomly presented 18 different renderings, representing the different experimental conditions. Participants were asked to rate their PLOC for bicycling under each scenario on a 10-point rating scale, from very uncomfortable (0) to very comfortable (10).

3.2. Participants

The current study was initially aimed at bicycling behavior among the general population of Oregon, with two lenient inclusion criteria: individuals between the ages of 18 and 75 years old were invited to participate in the research if they had bicycled in the past year. As such 10,000 random residential addresses across Oregon were purchased through a third-party company. Postcards were designed, printed, and mailed to these addresses, providing residents with a reusable link and unique household ID to participate in an online survey. Within the first two months, 182 responses were collected (1.82% response rate), which limited a comprehensive analysis of bicyclist behavior. To achieve statistically significant results, additional potential participants were contacted through various email listservs. These listservs were obtained

Table 1
Participant Bicycling Habits.

Bicycling Habit	Women		Men		Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Bicycling Frequency						
Daily	52	40.9	103	47.9	155	45.3
Weekly	42	33.1	73	34.0	115	33.6
Monthly	21	16.5	26	12.1	47	13.7
Other	12	9.4	13	6.0	25	7.3
Riding Purpose						
Commuting to work	54	42.5	98	45.6	152	44.4
Recreation	30	23.6	49	22.8	79	23.1
Exercise	24	18.9	36	16.7	60	17.5
Shopping	6	4.7	10	4.7	16	4.7
Other	13	10.2	22	10.2	35	10.2
Riding Duration						
< 10minutes	8	6.3	16	7.4	24	7.0
10–20 min	50	39.4	68	31.6	118	34.5
21–30 min	26	20.5	40	18.6	66	19.3
> 30minutes	42	33.1	89	41.4	131	38.3
Other	1	0.8	2	0.9	3	0.9
Downtown Experience						
Yes	111	87.4	197	91.6	308	90.1
No	16	12.6	18	8.4	34	9.9

through researcher connections with regional and national bicycling clubs. At the end of data collection stage, the online survey was successfully completed by 342 participants, including 127 women (M_{age} = 39.57, SD_{age} = 13.75) and 215 men (M_{age} = 44.79, SD_{age} = 15.20). Table 1 shows participant bicycling habits disaggregated by gender. Participants most frequently bicycled on a daily basis (45.3%), to commute to work (44.4%), and bicycled for more than 30 min per day (38.3%). Additionally, over 90% of participants had the experience of riding bicycle in a busy downtown.

3.3. Statistical analysis

Two types of variables are included in this study: with-in subject and between subject. To prevent the complicated statistical interpretation of multiway interactions, the analysis is divided into two sections. For the with-in subject variation, because each participant was exposed to all possible combinations of independent variables, repeated-measures analysis of variance (ANOVA) tests were performed with ambient traffic, pavement markings, and traffic signs as within-subject factors. Bicyclist PLOC was the dependent variable. Mauchly's sphericity test was used to confirm sphericity assumptions. A significance level of 0.05 was adopted. Tukey HSD adjustments were used for post hoc pairwise comparisons of estimated marginal means. Effect size was reported by using partial eta squared.

For the between subject variation, a k-means cluster analysis was performed to investigate the effect of gender and experience on PLOC. Cluster analysis addresses the problem of data segmentation by exclusively assigning each observation to one cluster during an iterative process. This method allows the subjects within a cluster to be similar to one another and different from subjects in other clusters. IBM SPSS Statistics software version 24 was used for data analysis.

4. Results

4.1. Repeated-measures ANOVA

Mean (M) and standard deviation (SD) values for PLOC results at each level of each independent variable are reported in Table 2. Participants bicycling in low traffic volumes with solid green bike lanes reported the highest mean PLOC values (M_{PLOC} = 7.67, SD_{PLOC} = 1.97). Participants bicycling in truck traffic with standard bike lane white markings without a warning sign reported the lowest mean PLOC values (M_{PLOC} = 4.07, SD_{PLOC} = 2.25).

Repeated-measures ANOVA tests were used to determine effects of factors on mean bicyclist PLOC. For pairwise comparisons, post hoc *t*-tests were conducted with refinement by Tukey's HSD test. Only statistically significant comparisons are discussed.

As shown in Table 3, factors of ambient traffic (F(2, 680) = 753.93, P < 0.001), and pavement marking (F(2, 680) = 64.36, P < 0.001) had significant effects on bicyclist PLOC. Pairwise comparison analyses showed that compared to low traffic volumes, bicyclists felt less comfortable with high traffic volumes (P < 0.001) or truck traffic (P < 0.001). PLOC was lower when bicycling with truck traffic than with high traffic volume (P < 0.001). Compared to the standard bike lane marking, bicyclists had higher PLOC values when they encountered solid green (P < 0.001) or dashed green markings (P < 0.001) in the conflict areas. PLOC did not differ between scenarios with solid or dashed green pavement markings.

Results of ANOVA revealed three statistically meaningful two-way interactions, which were subsequently inspected by pairwise comparisons (Fig. 2). There was a statistically significant interaction between the combined effects of ambient traffic and pavement marking on bicyclist PLOC (Fig. 2(a)) (F(4, 1360) = 16.50, P < 0.001). Pairwise comparison analysis showed that under high traffic volumes and truck traffic, compared to the standard bicycle lane with white marking condition, bicyclists felt more comfortable when conflict areas were identified by solid green (P < 0.001) or dashed green markings (P < 0.001). There was a statistically significant interaction between the combined effects of ambient traffic and warning sign on PLOC (Fig. 2(b)) (F(2, 680) = 13.73, P < 0.001). Under high traffic volumes, bicyclists had higher PLOC values when there was a warning sign (P = 0.048). Finally, there was a statistically significant interaction between the combined effects of pavement markings and warning signs on bicyclist PLOC (Fig. 2(c)) (F(2, 358) = 7.96, P = 0.001). It was found that bicyclist had higher PLOC values when solid green was used in conjunction with a warning sign (P = 0.001).

The simultaneous effects of the independent variables might be best described by the statistically significant three-way interaction. There was a main effect of the interaction of ambient traffic, pavement marking, and signage on PLOC (F(4, 716) = 4.53, P = 0.034) (Fig. 3).

Table 2
Mean and Standard Deviation Values of PLOC at Each Level of Each Independent Variable.

Ambient Traffic	Descriptive Statistics	White Lane Markings		Solid Green		Dashed Green	
		No Sign	Warning Sign	No Sign	Warning Sign	No Sign	Warning Sign
Low Traffic Volume	M	7.47	7.25	7.67	7.67	7.58	7.55
	(SD)	(2.13)	(2.09)	(1.96)	(1.97)	(1.99)	(2.02)
High Traffic Volume	M	5.43	5.52	5.90	6.11	5.91	6.08
	(SD)	(2.26)	(2.28)	(2.21)	(2.19)	(2.21)	(2.23)
Truck Traffic	M	4.07	4.15	4.41	4.49	4.45	4.49
	(SD)	(2.25)	(2.25)	(2.16)	(2.19)	(2.16)	(2.17)

Table 3
Repeated-Measures ANOVA Results on PLOC.

Source	$F(v_1,v_2)$	P	η_p^2
Within-Subject Factors			
Traffic	753.93 (2, 680)[a]	< 0.001	0.690
Pavement	64.36 (2, 680)[a]	< 0.001	0.160
Sign	2.91 (1, 340)	0.089	0.009
Traffic × Pavement	16.50 (4, 1360)[a]	< 0.001	0.046
Traffic × Sign	13.73 (2, 680)[a]	< 0.001	0.039
Pavement × Sign	7.96 (2, 680)[a]	0.001	0.023
Traffic × Pavement × Sign	4.53 (4, 716)[a]	0.034	0.013

Note: F denotes F statistic; v_1 and v_2 denote degrees of freedom; η_p^2denotes partial eta squared.

[a] Statistically significant at 95% confidence interval.

Results of pairwise comparisons showed that in low traffic volume with only white lane markings, participants had lower PLOC values when a warning sign was in place ($P < 0.001$). However, in high traffic volume, participants had higher PLOC values when a warning sign was in place in conjunction with either solid green or dashed green (all $P < 0.001$).

4.2. Cluster analysis

K-means cluster analysis was performed to analyze the effect of gender and bicycling experience on PLOC. Participants' gender and their self-reported experience in bicycling were considered as clustering variables and Squared Euclidian Distance was used as the base algorithm to assign each of the 342 participants to a single cluster through an iterative process. As such, four clustered were obtained: 1) Experienced men ($M_{Experience} = 9.25$, $SD_{Experience} = 0.77$), 2) Inexperienced men ($M_{Experience} = 5.92$, $SD_{Experience} = 1.38$), 3) Experienced women ($M_{Experience} = 8.85$, $SD_{Experience} = 1.10$), 2) Inexperienced women ($M_{Experience} = 4.38$, $SD_{Experience} = 1.53$). Table 4 shows the bicyclists PLOC in each of the clusters. One-way ANOVA was performed to compare the mean values of PLOC in each of the clusters and pairwise comparison with Tukey HSD refinement was used to find significant differences.

According to the cluster analysis results, a statistically significant effect of clustering was observed for all levels of independent variables except for low traffic volumes. Further pairwise comparisons showed that in high traffic volumes, experienced men and experienced women stated significantly higher PLOC values compared to those of inexperienced women ($P = 0.005$ and $P = 0.045$ respectively). In truck traffic, inexperienced women had lower PLOC values compared to experienced men ($P < 0.001$), inexperienced men ($P = 0.005$), and experienced women ($P = 0.026$). Pavement markings and signage were only perceived differently for experienced men and inexperienced women. Experienced men stated higher PLOC values compared to those of inexperienced women when white lane markings ($P = 0.001$), solid green ($P = 0.010$), and dashed green ($P = 0.008$) were in place. Additionally, under both levels of signage, experienced men had higher PLOC values than inexperienced women ($P = 0.002$ and $P = 0.007$ for no sign and warning sign respectively).

5. Discussion

Previous research showed that in urban areas, bicyclists and drivers prefer to travel in separate spaces, especially barrier-separated spaces. This separation significantly increases their level of comfort (Sanders, 2013). However, due to the limited right-of-way on streets in dense urban areas, barrier-separated or buffered bike lanes are less frequently implemented. Conventional bike lanes are often adopted as a safe and efficient practice. Conventional bike lanes designate an exclusive space for bicyclists through the use of pavement markings and signage (NACTO, 2011). However, bicycling next to vehicular traffic without physical separation could influence bicyclist PLOC. Decreased bicyclist comfort and confidence on busy streets could alter the behaviors and responses of bicyclists to traffic conflicts, thereby decreasing the tendency to use bicycles as a travel mode. This problem is even more critical when bicyclists, as vulnerable road users, experience conflicts with heavy vehicles in their negotiation of right-of-way near loading zones in dense urban areas. Engineering treatments, such as pavement markings and traffic signs, have been introduced as mitigation. It is important to investigate the extent to which these engineering treatments influence bicyclist PLOC.

In a repeated-measures ANOVA, effect size is measured by partial eta squared (η_p^2). Looking into the effect size would shed further light on the magnitude of the influence of independent variables on PLOC. In other words, effect size would allow measuring "how much" the ambient traffic, pavement marking, and warning sign have affected PLOC. In terms of the independent variables, ambient traffic had the highest effect on bicyclist PLOC while riding in conventional bike lanes, with 69% of within-subject variance being accounted for by ambient traffic. Regardless of engineering treatments and bicyclist characteristics, bicycling in high traffic volumes and truck traffic decreased PLOC values by an average of 22.5% and 42.4%, respectively. Colored pavement markings near loading zones increased bicyclist PLOC values. Pavement marking accounted for 16% of the within-subject variance. Regardless of ambient traffic and warning sign, on average, PLOC was increased by 6.9% when participants encountered colored pavement markings in conflict areas when compared to the condition with a standard bike lane with white markings.

Observed effect size of independent variables reveals a critical fact about the findings of the present study. While engineering treatments such as pavement markings and warning signs are effective under specific circumstances, their effectiveness is less obvious compared to that of ambient traffic. Indeed, while 69% of the change in PLOC is accounted for by ambient traffic, it is only 16% for pavement markings and approximately 1% for the warning sign. This finding explicitly confirms that compared to ambient traffic, the engineering treatments considered in this survey created limited variability in with-in subject observations. In other words, in a dense urban environment, the presence of a truck could significantly affect bicyclist PLOC such that the impact of NACTO recommended engineering practices could be

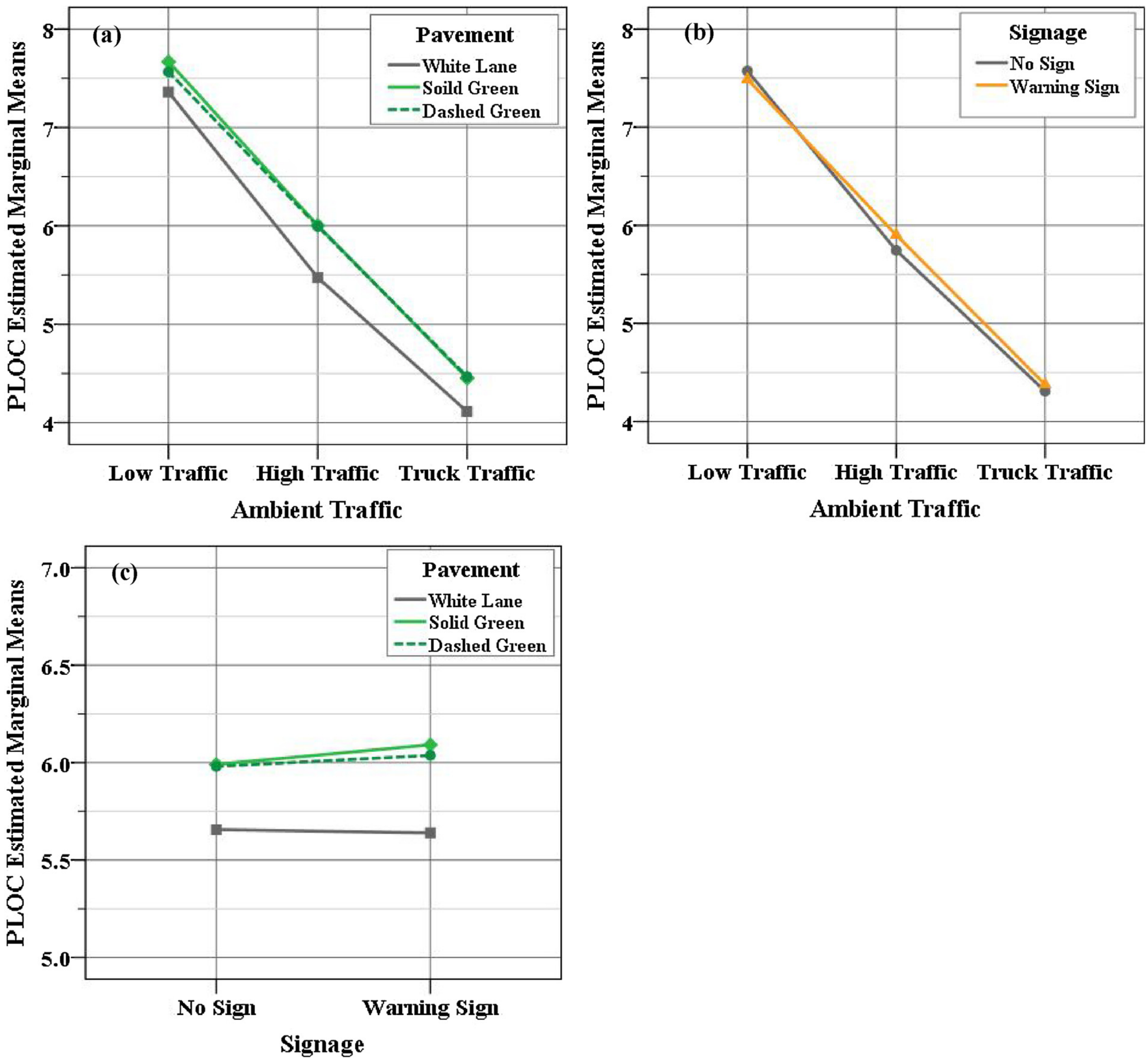

Fig. 2. Statistically Significant Two-Way Interactions, According to ANOVA.

mediated by this stressful situation.

The factorial design of the survey and the results of repeated-measures ANOVA make it possible to consider the interaction effects of the independent variables. Although there was a main effect of pavement markings on bicyclist PLOC, this variable did not operate as a dispositional determinant independent of ambient traffic. Indeed, the positive effect of pavement markings only held under conditions of high traffic volume (9.6% increase in PLOC) and truck traffic (8.6% increase in PLOC). Under all traffic conditions, bicyclists had similar PLOC values when they encountered solid or dashed green pavement markings. Thus, the presence of pavement markings along the bike lane at conflicts areas seems to be more relevant than the striping pattern. Additionally, while no direct effect was observed for signage, it was found that this type of engineering treatment could play an important role in conjunction with other variables. As shown on Fig. 3, in low traffic volume and with white lane markings, presence of a warning sign decreased PLOC values by average of 2.9%. However, in high traffic volume and with colored pavement markings, presence of a warning sign increased PLOC values by average of 3.6%. This is an interesting finding which replicates two different bicycling conditions. In low traffic volume, when the warning sign is the only safety component in place, it is interpreted by bicyclists as an alarm to inform them of a potential conflict on the road, therefore decreasing their PLOC. However, in high traffic volume, when this type of engineering treatment is placed in conjunction with colored pavement markings, it may have helped bicyclist's interpret the overall condition as a means to reinforce their right-of-way and to increase their visibility, resulting in higher PLOC values. This finding confirms that these engineering treatments help road users identify potential conflicts and feel more comfortable.

Finally, the influence of gender and bicycling experience on PLOC was found to be context-specific and varied in intensity depending on ambient traffic and engineering treatment. Women and men with various bicycling experience had similar PLOC results for bicycling in low traffic volumes. However, PLOC results differed significantly between experienced men and inexperienced women under all other levels of independent variables. Notably, compared to experienced men, inexperienced women reported decreased PLOC values in high traffic by average of 20.9% and in truck traffic by average of 38.3%. This finding could be a substantial hindrance in promoting bicycling among all groups of a sustainable society. In other words, the significant decrease in bicycling PLOC for inexperienced women in high traffic and truck traffic could influence their choice of selecting bicycling as a travel mode, especially for commuting to work in dense urban areas, perpetuating their self-identification as "inexperienced bicyclists". While the significant difference is observed in all situations, the role of

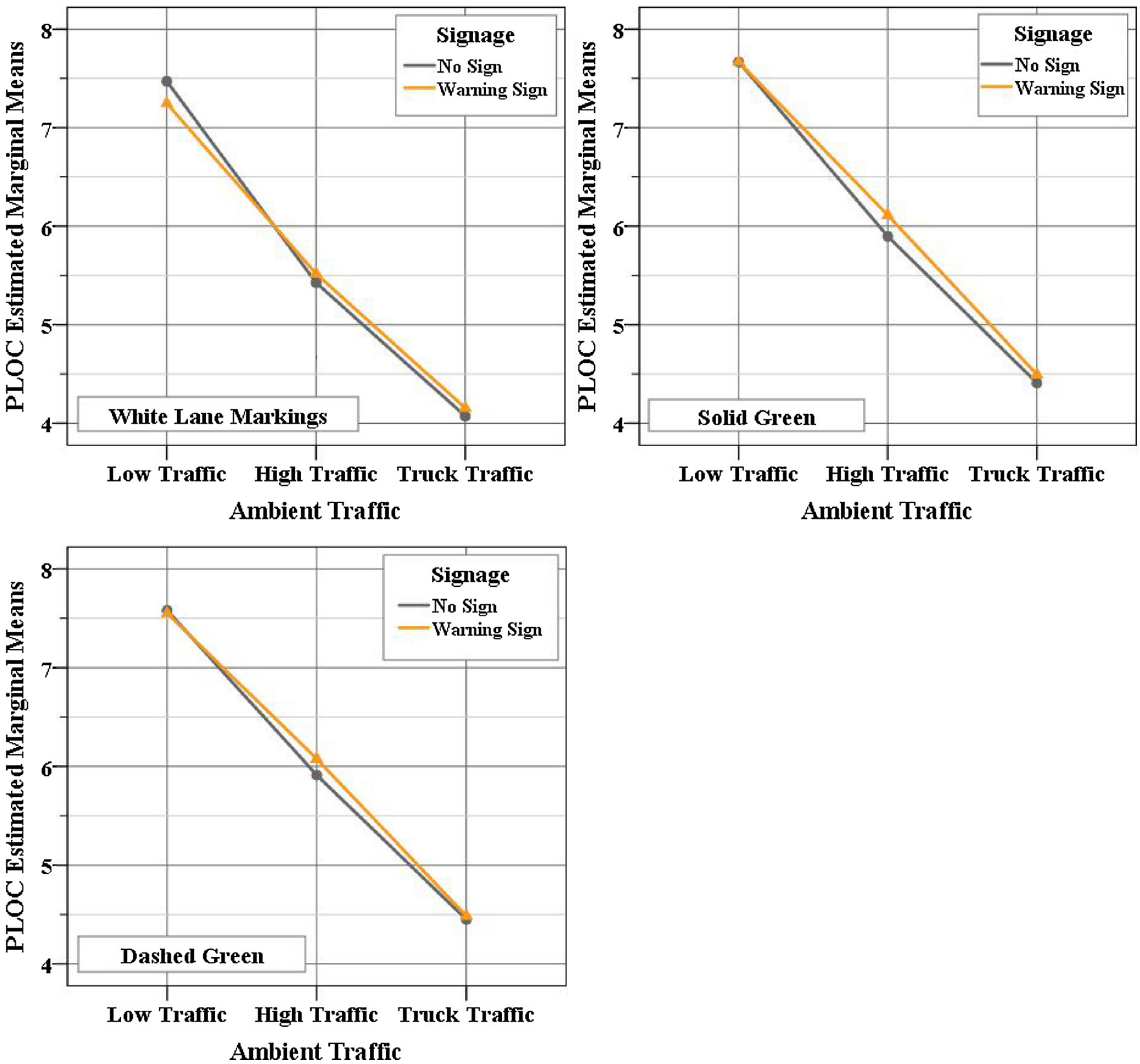

Fig. 3. Statistically Significant Three-Way Interaction, According to ANOVA.

engineering treatments is promising. Fig. 4 depicts PLOC values of experienced men and inexperienced women in truck traffic with and without engineering treatments. As shown by this figure, while the presence of warning sign in addition to colored pavement markings help to reduce the PLOC sparsity among inexperienced women, it significantly decreases the difference between the median PLOC values for experienced men and inexperienced women as two distinct groups of road users.

Table 4
Cluster Analysis Results on PLOC.

Factor	Cluster 1 Experienced Men (n = 162)		Cluster 2 Inexperienced Men (n = 53)		Cluster 3 Experienced Women (n = 90)		Cluster 4 Inexperienced Women (n = 37)		*F*	*P*
	M	SD	M	SD	M	SD	M	SD		
Ambient Traffic										
Low Traffic	7.63	1.87	7.41	1.63	7.58	2.06	7.16	1.90	0.72	0.539
High Traffic	6.09	2.10	5.68	1.99	5.89	2.21	4.82	2.00	3.84	0.010
Truck Traffic	4.78	2.20	4.44	1.88	4.10	2.15	2.95	1.44	8.30	< 0.001
Pavement Markings										
White Lane Markings	5.97	1.93	5.52	1.82	5.60	2.04	4.67	1.69	4.79	0.003
Solid Green	6.28	1.89	6.03	1.71	6.01	1.98	5.22	1.54	3.30	0.021
Dashed Green	6.26	1.88	5.99	1.68	5.96	2.06	5.17	1.56	3.47	0.016
Signage										
No Sign	6.15	1.85	5.87	1.70	5.80	1.96	4.97	1.60	4.31	0.005
Warning Sign	6.18	1.90	5.81	1.74	5.92	1.99	5.08	1.58	3.64	0.013

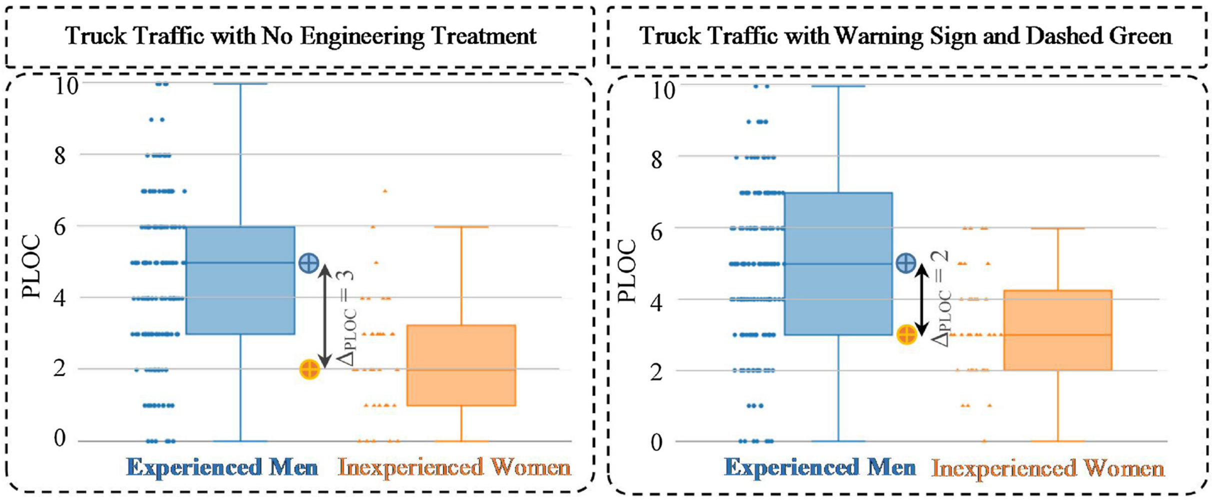

Fig. 4. PLOC Values in Truck Traffic by Engineering Treatment and Bicyclist Characteristics.

6. Summary and conclusion

This study attempted to quantify the factors influencing bicyclist PLOC near loading zones in dense urban environments. A factorial design was developed with ambient traffic (high traffic volume, low traffic volume, and truck traffic), pavement markings (white lane markings, solid green, and dashed green), and traffic signs (no sign and warning sign) as within-subject factors. Three-dimensionally rendered images were produced to represent 18 bicycling scenarios at each level of each independent variable. Participants were shown rendered images and asked to rate their PLOC for bicycling on a 10-point rating scale. An online survey was designed and distributed among potential participants, with 342 participants (127 women, 215 men) successfully completing the survey.

Repeated-measures ANOVA tests were used on the mean bicyclist PLOC values to identify effects and interactions of independent variables. A main effect was identified for ambient traffic and pavement markings individually, and statistically significant two- and three-way interactions were also found. When bicycling on a conventional bike lane, participants reported that ambient traffic, especially truck traffic, had the most significant effect on their PLOC. Truck traffic in the adjacent lane reduced bicyclist PLOC by more than 42%. Pavement markings were more effective than traffic signs, but no difference was observed between solid and dashed green pavements. Finally, the effect of gender and bicycling experience on PLOC was not universal, but varied with different levels of traffic and engineering treatments. Women were more affected than men by the presence of a truck in the adjacent lane but they were also more prone to a considerable increase in PLOC values due to the implementation of engineering treatments.

The findings of this study could aid in the development of future policies regarding bicycling infrastructure in several ways. First, alternative bike lane designs should be considered in conjunction with predominant traffic conditions at loading zone locations. More than 42% of participants in this study ($n = 145$) reported extremely low PLOC values (≤ 3) when they encountered truck traffic. This finding suggests that bicyclists feel uncomfortable riding in a standard bicycle lane adjacent to a vehicular travel lane, especially if trucks are prevalent in the traffic stream. Under such traffic conditions, some form of physical separation should be considered. Second, engineering treatments could be utilized as an effective method to increase bicyclist PLOC. Although colored pavement markings and warning signs are both effective, they differ in the magnitude and direction of their influence. Priority should be given to pavement markings, which appear to be more effective than signs in increasing bicyclist PLOC in conflict areas near urban loading zones. Bicyclists did not perceive various striping patterns (solid vs. dashed) differently when presented adjacent to loading zones. Therefore, other influential factors, such as technical and economic considerations, could be used to select the final striping pattern. Finally, characteristics of road users should be addressed when considering alternative designs. Although male and female bicyclists with various bicycling experience had the same PLOC in low traffic volumes, their PLOC differed substantially when bicycling in high traffic volumes or with truck traffic. Bicycling has long been promoted as a form of social equity. However, the gender-related challenges for bicycling in dense urban environments could play against the notion of social equity in transportation planning. Lower PLOC prevents women, who are huge stakeholders in today's transportation decisions, from using bicycles. As such, engineering treatments that are perceived to increase cycling comfort by inexperienced female bicyclists could hugely benefit urban transportation planning and design.

This study was limited in the way that data was collected. While all the efforts were made to obtain a random sample of a general population, the final sample was skewed toward more experienced bicyclists. This could be due to the fact that the survey used in this experiment was quite large and no incentive was provided for participants. As such, people who are inherently interested in bicycle issues were more predominant among the final sampling.

Some challenges may be associated with the specific engineering treatments that are found to be effective in increasing bicyclist PLOC. Indeed, colored pavement markings within a bike lane are supposed to increase visibility and reinforce right-of-way priority for bicyclists in potential conflict areas. The findings of this study confirmed that bicyclists are interpreting these treatments accordingly. However, the effect of these treatments should also be examined from the motorist's perspective. Future research should investigate whether motorists perceive the engineering treatments to be beneficial to bicyclists, and whether these treatments encourage motorists to be more cautious in looking for bicyclists on the road.

While PLOC seems to be influential on bicyclist safety during conflicts with truck traffic, it has yet to be documented in the literature. This may be because PLOC is a qualitative measurement, related to perception of individual bicyclists, but actual safety is a quantitative measurement related to the fatality and injury outcomes in bicycle and truck crashes. An appropriate next step would be to analyze the interaction of PLOC and bicyclist safety. This could be achieved through simulation experiments where bicycle and truck interactions could occur in a safe immersive environment where variables could be favorably controlled or measured.

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