Transportation Research Part A 91 (2016) 120–133

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

We can all get along: The alignment of driver and bicyclist roadway design preferences in the San Francisco Bay Area

Rebecca L. Sanders

Toole Design Group, 319 SW Washington Street, Suite 800, Portland, OR 97204, United States

ARTICLE INFO

Article history:
Received 9 March 2014
Received in revised form 4 March 2016
Accepted 10 June 2016
Available online 7 July 2016

Keywords:
Bicycle facilities
Roadway design
Bicyclist design preferences
Driver design preferences
Bicycle lanes

ABSTRACT

Two trends in the United States—growth in bicycling and enthusiasm for complete streets—suggest a need to understand how various roadway users view roadway designs meant to accommodate multiple modes. While many studies have examined bicyclists' roadway design preferences, there has been little investigation into the opinions of non-bicyclists who might bicycle in the future. Additionally, little research has explored the preferences of the motorists who share roads with cyclists—despite the fact that motorists compose the vast majority of roadway users in the United States and similarly developed countries.

This paper presents results from an internet survey examining perceived comfort while driving and bicycling on various roadways among 265 non-bicycling drivers, bicycling drivers, and non-driving bicyclists in the San Francisco Bay Area. Analysis of variance tests revealed that both drivers and bicyclists are more comfortable on roadways with separated bicycling facilities than those with shared space. In particular, roadways with barrier-separated bicycle lanes were the most popular among all groups, regardless of bicycling frequency. Striped bicycle lanes, a common treatment in the United States, received mixed reviews: a majority of the sample believed that they benefit cyclists and drivers through predictability and legitimacy on the roadway, but the lanes were rated significantly less comfortable than barrier-separated treatments—particularly among potential bicyclists.

These findings corroborate research on bicyclists' preferences for roadway design and contribute a new understanding of motorists' preferences. They also support the U.S. Federal Highway Administration's efforts to encourage greater accommodation of bicyclists on urban streets.

1. Introduction

Increasing bicycling trips has been national policy in the United States since the U.S. Department of Transportation set its 1994 goal to double the U.S. cycling rate (FHWA, 2004). Twenty years later, data from national transportation surveys show that bike commuting has increased an average of 47% in major U.S. cities over the last decade (Flusche, 2012). In some cities, such as Lexington, Kentucky, and Portland, Oregon, the percentage of bike commuters has grown over 300% since 2000, and many other U.S. cities have seen growth in excess of 100–200% (Flusche, 2010; Pucher et al., 2011). Given this trend toward increased cycling and potentially commensurate increased conflict over limited roadway space, efforts to design and build roadways that accommodate multiple types of roadway users—also known as "complete streets"—have intensified. In fact,

E-mail address: rsanders@tooledesign.com

http://dx.doi.org/10.1016/j.tra.2016.06.002
0965-8564/

over 665 regional and local jurisdictions, including 60% of U.S. states, have already adopted complete streets policies or made a written commitment to do so (National Complete Streets Coalition, 2014).

To complement the movement toward complete streets, practitioners need an understanding of roadway designs that maximize comfort and safety for all roadway users. This paper presents findings from research exploring perceptions of adult bicycling risk, experiences bicycling, and roadway design preferences among bicycling drivers, non-bicycling drivers, and non-driving bicyclists in the San Francisco Bay Area (Author, 2013). The results corroborate research showing that bicyclists of all types—and particularly potential cyclists—prefer greater separation from motorists. Additionally, the results provide new information about motorists' preferences for sharing the road with bicyclists, indicating that motorists also prefer greater separation. These findings suggest an alignment between roadway user groups' design preferences for multi-lane, commercial streets, and provide additional evidence of the benefits of complete streets for all roadway users. Methodologically, these findings also suggest advantages from studying the preferences of multiple user groups regarding shared facilities.

2. Literature review

2.1. Bicyclists' roadway design preferences

Internationally, studies examining current—and sometimes potential—bicyclists' roadway design preferences are diverse and plentiful, though they have not directly considered motorists' design preferences for sharing the roadway with bicyclists. Many of those studies have found that bicyclists generally prefer a separate space from motorists. For example, in their online survey of 1605 Texas cyclists, Sener et al. (2009) found that nearly 80% of respondents characterized the overall quality of bicycle facilities in their communities as "inadequate" or "very inadequate". Similarly, in their telephone survey of 566 Portland, Oregon, residents, Dill and Voros (2007) found that 37% of those who wanted to bicycle more reported that there were not enough bike lanes or trails near where they wanted to go. Haworth and Schramm (2011) surveyed 2523 adult cyclists in Queensland, Australia, and found that utilitarian bicyclists were hesitant to ride on the roadway and often rode on the sidewalk—particularly if they were new to bicycling.

Winters and Teschke (2010) used a combination phone and internet survey to evaluate the roadway design preferences of approximately 1400 cyclists of all experience levels (including potential cyclists, defined as those who owned a bike and would consider bicycling in the future). As one of the first studies to ask about separated, on-street bicycle facilities in North America, they found that a concrete-barrier-separated cycle path on a major street was the fourth-ranked (out of sixteen) option for potential and occasional cyclists (after off-street paths and traffic-calmed neighborhood streets with and without bicycle markings), and ranked second and third, respectively, for regular and frequent cyclists. In contrast, major city streets without bicycle facilities were the least preferred by all respondents. Studies conducted since have found similarly strong preferences—particularly among potential cyclists and women—for separated bicycle facilities (Dill and McNeil, 2013, N = 908; McNeil et al., 2015, N = 2283).

Recognizing that people do not make travel choices in a vacuum, some studies have sought to define the "value" of a certain bicycle facility in terms of travel time. In their adaptive stated preference survey of a convenience sample from the University of Minnesota, Minneapolis, Tilahun et al. (2007) presented 167 participants with ten-second videos featuring two routes with different bicycle facilities and associated travel times. A computer-adapted choice sets in response to participants' selections until a final facility value was reached. A utility model of the data revealed that the average respondent was willing to travel the farthest to avoid a street with on-street parking but no bike lane. In general, the presence of a bicycle lane had a much greater impact on the odds of choosing the higher quality facility than did the elimination of on-street parking or the presence of an off-road facility. This tendency was magnified among women, and not significantly influenced by cycling experience.

Similarly, Parkin et al. (2007) used video to present their 144 survey participants with various route options for bicycling in Bolton, United Kingdom. Models created from user ratings of the facilities, although resulting in a relatively low R^2 (maximum of 0.275), suggested that the presence of a striped bicycle lane on any road type decreased perceived risk, while the presence of on-street parking increased perceived risk along residential roads. It should be noted that neither of these studies offered route options with green or separated bicycle lanes.

More recently, in their stated preference survey of 1941 people working in Dublin, Ireland, Caulfield et al. (2012) found that an "off-road cycle lane" (essentially a curb-separated bicycle lane) was the most preferred bicycle facility, even compared to a greenway/bicycle trail. This preference held regardless of respondents' self-reported confidence levels, although the effect was stronger for less confident cyclists, as would be expected.

Other bicycling research has monitored route choice in an effort to understand the attractiveness of certain roadway designs when built. While this data is limited to built bicycle treatments, it can provide important information to compare with stated preference findings. Winters et al. (2010) used reported routes from 74 participants in their Vancouver bicycling study to examine the distance people detour from the shortest path to use a bicycle facility. They found that bike trips were significantly more likely to occur along routes with enhanced bicycle facilities including traffic calming, stencils, and signage; while only 21% of trips would be along designated bike routes in a shortest path scenario, on average, 49% of actual trip distance took place along a bike route. They also found that participants who reported being discouraged from cycling because of perceived traffic risk were more likely to detour, although the small sample size limits the generalizability of the results. Similar results were found in Oregon: Broach et al. (2012) used GPS monitors to gather data on the routes of 164 cyclists over several days in Portland. They were then able to build a model based on revealed, real-time preferences that could account for trade-offs in topography, traffic volumes, and street network characteristics. They found that cyclists travel out of their way to reach bicycle infrastructure, particularly bicycle boulevards, which comprised 1% of the network, but carried 10% of all utilitarian bicycle travel.

2.2. Motorists' roadway design preferences: a gap in the literature

Despite the recent investigation into cyclists' roadway design preferences, little research has examined the preferences of the motorists who routinely share the road with cyclists, although corollary benefits and detractions for motorists have been studied. For example, Marshall and Garrick (2011) examined the value of increased bicycling for overall roadway safety, finding that cities with higher numbers of cyclists had lower injury severity levels for all road users. Research exploring the impact of separated bike lanes in several U.S. cities asked residents about the desirability of their neighborhood after separated bike lanes were installed and found that, of the nearby residents who self-classified as motorists, over twice as many perceived an increase in desirability as those who did not, despite the fact that they did not bicycle in the lanes (Monsere et al., 2014, N = 2283). In a phone survey of 332 registered voters in Portland, Oregon, and San Francisco, California, a majority of respondents reported positive perceptions of roadways with separated and buffered bike lanes, versus roadways without such facilities (Andersen, 2013).

However, no research has explicitly asked motorists their roadway design preferences for sharing the road with cyclists—an important question given the needs of practitioners to balance safety and throughput for all roadway users and the increasing likelihood of cyclists and motorists sharing streets worldwide. The research presented in this paper contributes to this gap in the literature by examining the roadway design preferences of drivers and comparing them to the preferences of potential and current cyclists. Additionally, this research delves into positive and negative perceptions of bicycle lanes in order to more fully understand some of the motivation behind the drivers' preferences. It is hoped that this information will expand the scope of research carried out in this field and aid roadway designers seeking solutions appealing to all user groups.

3. Methodology

3.1. Survey construction and recruitment

The findings presented in this paper are based on research investigating the effects of knowledge, attitudes, behaviors, and experiences of bicyclists and drivers on perceived and actual bicycling risk in the San Francisco Bay Area. In July 2011, a link to an online survey was emailed to a convenience sample of 1177 people who had previously participated in transportation research with UC Berkeley. Respondents were offered an incentive of a $5 gift card to a local store upon completion of the survey. There were 463 valid, completed surveys from email list respondents, resulting in a known response rate of 39%. Part of the survey was optional for people who bicycled, but required for those who did not bicycle. As a result, the sample size for the optional part was reduced to 229 cyclists and 265 drivers; 222 respondents completed this section as both a driver and a cyclist. The results in this paper pertain to this sub-sample.

The survey asked respondents about socio-demographic information and a variety of aspects of bicycling risk, including experiences bicycling or driving near bicyclists; beliefs about bicycling in general; safe and unsafe practices of bicyclists and drivers; attitudes toward cycling in the respondent's city; opinions about potential cycling laws; knowledge of current cycling laws; and preferences for roadway design. This survey focused on driver-bicyclist interactions and did not ask questions about pedestrian-bicyclist interactions. The survey was developed based on a thorough literature review about bicycling and bicycling risk, as well as the results of several focus groups which are described in greater detail in the following section.

Matching the method used in a survey by Dill and Voros (2007), respondents were categorized according to how often they bicycled for "work/school or errands" and/or recreation. If the respondents reported less than once per year for both categories, they were asked if they would consider bicycling for either reason in the future. The categories equated to the following (numbers in the sub-sample presented in this paper):

- *Non-cyclist* (n = 36): a respondent who reported never bicycling, or bicycling less than once per year for either utilitarian or recreational purposes, who would not consider bicycling for any reason in the future.
- *Potential cyclist* (n = 74): a respondent who reported never bicycling, or bicycling less than once per year for either utilitarian or recreational purposes, who indicated a willingness to consider bicycling for any reason in the future.
- *Occasional cyclist:* a respondent who reported bicycling at least a few times per year for any purpose, but less than several times a week.
    - o *Subset 1 – Yearly cyclist* (n = 51): a respondent who reported bicycling at least a few times per year for any purpose, but less than several times per month.

  - o *Subset 2 – Monthly cyclist* (n = 38): a respondent who reported bicycling at least several times per month for any purpose, but less than several times a week.
- *Regular cyclist:* a respondent who reported bicycling at least several times per week for any purpose.
  - o *Subset 1 – Weekly cyclist* (n = 48): a respondent who reported bicycling at least several times per week for any purpose, but not daily.
  - o *Subset 2 – Daily cyclist* (n = 18): a respondent who reported bicycling every day for any purpose.

This findings presented in this paper pertain to the section of the survey exploring roadway design preferences. In this section, respondents were asked to indicate their comfort or discomfort on a series of eight multi-lane, commercial roadway designs while (1) driving near bicyclists, and (2) bicycling near motorized traffic. They were told to "assume that the car traffic is traveling 25–30 mph" (40–48 kph). Comfort was rated on a seven-part Likert scale, with a neutral option and the modifiers "somewhat", "moderately", and "very" comfortable or uncomfortable. All of the photos, displayed together in Fig. 1, were manipulated through Adobe Photoshop to show a variation on the original roadway design. Respondents were presented with the photos one-at-a-time, and the photos were randomized within each survey to control for ordering effects. Respondents did not know which designs the choice set contained.

The data in this paper were analyzed through Kruskal Wallis (a non-parametric version of the ANOVA test that can be used with ordinal data) and Chi Square tests using Microsoft Excel (Microsoft, Redmond, WA) and STATA IC, Version 12 (StataCorp, College Station, TX).

3.2. Focus groups

Focus groups were conducted as a secondary methodology to both inform survey development and supplement the survey findings. The four 1.5-h focus groups consisted of an average of eight Bay Area residents each, approximately balanced in gender and ranging in age from 23 to 75. The groups were held in February and March 2011. Participants were solicited from UC Berkeley, churches, and a local pedestrian and bicycling advocacy organization, and offered a meal in exchange for their time. Participants from local churches tended to be older and much less likely to bicycle, while participants from UC Berkeley and the advocacy organization generally bicycled more than the average population. In this way, both groups provided unique insights into the survey development and subsequent findings.

The focus groups were conducted in a semi-structured manner, such that participants were asked specific questions but allowed some liberty to steer the discussion to topics of greater interest. The groups were recorded with participants' permission, and results coded to understand key themes (e.g., barriers to bicycling, motorists' perceptions of bicycling, reactions to roadway designs), which were then further examined through the survey. More detail about the entire project, including a copy of the focus groups and survey, can be found in Author (2013).

3.3. Limitations

As with all surveys, there may be some bias because people are more likely to respond when interested in a subject—particularly for optional sections like the design preference section. In addition, the eight roadway designs did not represent a complete set of designs available; there may be roadway designs that respondents would have preferred more or less than the ones discussed in this paper. Furthermore, the roadway design ratings were not based on an adaptive stated preference framework, and thus cannot be said to represent ratings that have fully considered trade-offs between features (for example, the loss of parking in some cases). It also cannot be guaranteed that all respondents held the same definition of "comfort" when answering the questions.

Additionally, the number of daily cyclists in the sample is small. "Daily cyclist" was defined as someone who rides every day, meaning that people who ride almost every day are categorized as weekly cyclists (people who ride many times a week, but not every day). Daily cyclists are kept as a separate group because their responses differ significantly from weekly cyclists in some ways. Moreover, there are relatively few daily cyclists in most U.S. cities, so analyzing them separately can help provide practitioners and researchers with insights about this small group. Future research to further investigate the scope and magnitude of difference between weekly and daily cyclists would be beneficial.

Finally, it is possible that photos "d" and "e" in Fig. 1 were underrated due to the car parking somewhat in the lane. While this underrating may have occurred, the car in the original photo was parked in the lane, so the altered photos depict a very real possibility.

4. Results

4.1. Characteristics of the survey population

Table 1 presents a snapshot of the survey sub-sample population (a similar snapshot of the entire survey sample is located in Table A1 of the Appendix). The data indicate that, not surprisingly, weekly and daily cyclists are significantly younger than non-cyclists, and there are significantly fewer female monthly and daily cyclists. There were almost as many female weekly cyclists as male, a split that may reflect response bias given that Census data from various counties in the Bay

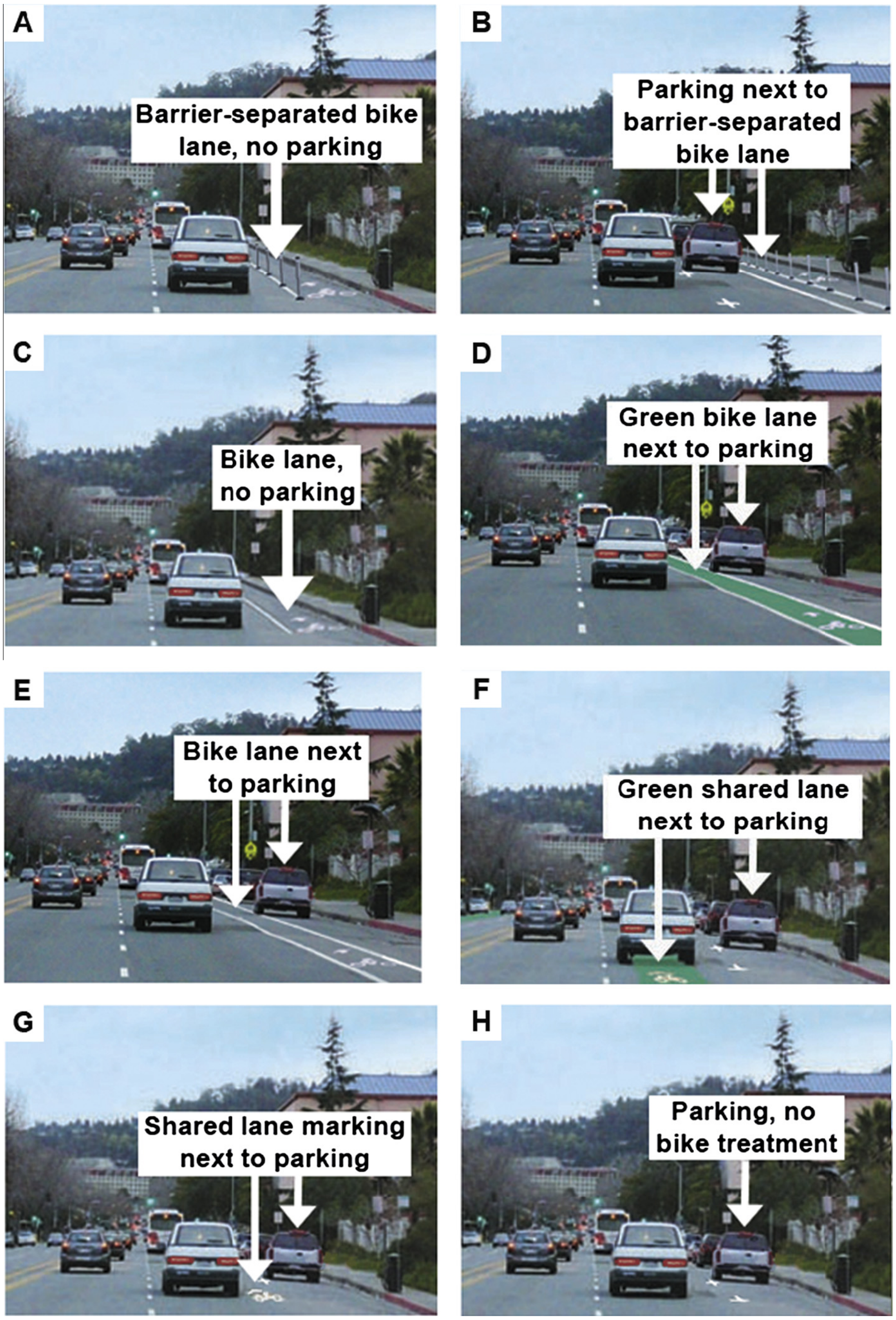

Fig. 1. Eight options for a multi-lane, commercial roadway.

Area indicate that men bicycle for work from 1.75 to 5 times more than women (American Community Survey, 2006–2010). The cycling groups also varied according to the distribution of races and ethnicities, with monthly and weekly cyclists having the highest percentages of white, non-Hispanic respondents. While this seems to fit with most research on bicycling, which tends to have a high percentage of white respondents, it is not clear if this proportion more accurately reflects how often certain groups bicycle or how often certain groups respond to surveys about bicycling. Future research specifically investigating cycling within non-white populations would help round out these findings.

In terms of driving frequency, the distribution between cycling groups follows the expected direction, with the driving frequency significantly ($p \leqslant 0.0001$) negatively associated with the bicycling frequency. However, the large majority of

Table 1
Survey population characteristics (N = 265).

	Non-cyclists (n = 36) %	Potential cyclists (n = 74)%	Yearly cyclists (n = 51)%	Monthly cyclists (n = 38)%	Weekly cyclists (n = 48)%	Daily cyclists (n = 18)%	Total (N = 265)%
Age							
18–24	6	–	8	3	8	6	5
25–34	31	35	20	39	38	39	33
35–44	8	18	14	5	21	17	14
45–54	11	24	41	29	21	11	25
55–64	28	20	14	21	13	28	19
65–74	14	3	4	3	–	–	4
75+	3	–	–	–	–	–	–
	Kruskal Wallis significant ($p \leqslant 0.01$)						
Sex							
Male	25	35	53	68	50	67	47
Female	75	64	47	32	48	33	52
	Chi-square significant ($p \leqslant 0.001$)						
Race/Ethnicity							
White, non-Hispanic	53	66	63	79	75	61	67
Hispanic	8	3	4	3	2	–	3
African American or Black	8	8	4	–	2	–	5
Asian	8	11	8	5	8	22	9
Other races	11	7	10	13	10	6	9
Two or more races	6	4	6	–	–	6	3
Decline to say	6	1	6	–	2	6	3
	Kruskal Wallis not significant						
Driving frequency[a]							
Never	–	–	4	5	4	–	2
Less than once per week	6	3	6	13	10	33	9
One to three days per week	22	32	14	16	42	56	28
Four or more days per week	72	64	76	66	44	11	60
	Kruskal Wallis significant ($p \leqslant 0.0001$)						
Annual household income							
Less than $35,000	19	19	10	16	15	11	15
$35,000–$49,999	11	14	4	5	8	–	8
$50,000–$74,999	22	15	22	16	27	11	19
$75,000–$99,999	14	18	12	13	15	11	14
$100,000–$149,999	14	12	31	18	15	50	20
$150,000 or more	6	12	12	16	10	11	11
Decline to say	14	11	10	16	10	6	11
	Kruskal Wallis not significant						
Children < Age 16 in household							
Yes	6	18	29	24	17	17	19
	Fisher's exact marginally significant ($p \leqslant 0.10$)						

[a] "Driving frequency" refers to how many times per week the respondent drives a car.

respondents drive at least once a week, irrespective of bicycling frequency. There was no significant difference between groups regarding income, and only a marginally significant difference ($p = 0.092$) regarding the presence of children under aged 16 in the household.

Table 2 compares the survey sub-sample with the full survey sample and the larger Bay Area population. Note that the survey sub-sample is similar to the full sample except for an even greater proportion of white, non-Hispanic respondents. In comparison to the Bay Area population, both the sub-sample and the full sample are disproportionately composed of 25–34 year-olds and white, non-Hispanic respondents, and includes fewer respondents from both the very low and very high ends of the income spectrum. The data were not weighted to address these differences, as the respondents, having been solicited through a convenience sample, may have systematically differed from the general population in unknown ways and weighting would not have not reliably addressed this potential bias.

4.2. Perceptions of comfort for roadway design

The data indicate an alignment in preferences between cyclists of differing experience levels, regardless of bicycling purpose, and drivers. Fig. 2 displays the percentage of drivers feeling "moderately" or "very" comfortable driving near cyclists in each scenario. Fig. 3 displays the percentage of cyclists feeling "moderately" or "very" comfortable bicycling near motorists in each scenario.[1] Recreational and utilitarian cyclists are combined for Fig. 3, given that the ratings and significant differences between groups followed the same pattern for both types of cyclists. Both figures show combined ratings for "moderately" and "very" comfortable in recognition of the fact that some people, particularly those with little or no cycling experience, may not feel "very" comfortable on any treatment.

There are several points to note from the data represented in these figures. First, there are only two roadway designs for bicycling that evenly appeal to all groups, regardless of cycling frequency: the two barrier-separated bicycle lane designs shown in photos A–B of Fig. 1. These two designs are also the most appealing for both cyclists and drivers, although there is a marginally significant difference ($p \leqslant 0.05$) between driver ratings according to bicycling frequency. Comments from the focus groups support these findings: there was general approval of the facility among all participants, with one remarking, "This (barrier-separated bike lane in Photo A) says that this lane is safe for adults and kids and all different kinds of cyclists; you'd be relaxed in (cycling)."

Second, more current cyclists than potential cyclists would feel at least moderately comfortable bicycling on all roadway designs except the barrier-separated bicycle lane without parking, suggesting that this design may be critical to attracting new cyclists. This corroborates research on cycling experience and preference for separation from traffic and parking (Winters and Teschke, 2010; Dill and McNeil, 2013; McNeil et al., 2015). Third, a higher percentage of respondents ranked each treatment at least moderately comfortable as a driver than as a cyclist, again except for the barrier-separated lanes, which were rated at least moderately comfortable by approximately the same percentage of respondents for both scenarios.

The cyclists' comfort ratings indicate the following order of preference regarding roadway design:

(1) Barrier-separation between moving non-motorized and motorized traffic.
(2) Separation from parked cars.
(3) Visual demarcation of space using paint (e.g., the green painted bicycle lane).
(4) Visual demarcation of legitimacy using paint (e.g., the shared green lane or shared lane marking).

This order is particularly pronounced for potential cyclists. While comfort levels for current cyclists remain close for the barrier-separated treatments and the bicycle lane without on-street parking, Fig. 3 shows that potential cyclists' comfort levels clearly drop once barriers are no longer part of the design. They drop once again when parking is introduced without a barrier—even in the case of the green bicycle lane (photo D in Fig. 1), a design for which only 41% of potential cyclists feel at least moderately comfortable. Beyond the green bicycle lane, the percentage of potential cyclists who feel at least moderately comfortable is very low ($\leqslant$20%). In contrast, a majority of current cyclists still feel at least moderately comfortable using the green bicycle lane. However, comfort for these groups clearly drops in the case of a striped bicycle lane next to parking (photo E in Fig. 1), and declines dramatically for all options that lack a separated, marked space for cyclists.

The first three priorities for roadway design for cyclists also reflect drivers' preferences. A large majority of all groups rated the separated (by barrier or paint) designs as at least moderately comfortable for driving near bicyclists. This finding was supported by comments from the focus groups, indicating a unanimous desire among non-cycling drivers for bicycle treatments that clearly indicate what to expect and where. As one participant stated, "If bikes are going to be on (the road), I'd prefer it to be marked."

However, only 41% of non-cycling drivers (including drivers who are potential cyclists) rated the shared lane markings ("sharrows", photo G in Fig. 1) as at least moderately comfortable for driving near bicyclists, and, with the exception of those who bicycle daily, less than 43% of all groups rated the green[2] shared lane (photo F in Fig. 1) as such. Comments from the focus group participants suggest that these low ratings reflect uncertainty about how to behave—and how bicyclists will behave—i n situations with shared space, particularly regarding the green shared lane. For example, one non-cycling driver stated that the green share lane "...makes me very uncomfortable;" another participant said he didn't "understand how it works" (a concern also lodged against the sharrow).

In general, cycling drivers were more enthusiastic about the shared space treatments than non-cycling drivers, likely because they were able to picture themselves cycling and imagine how to behave—and how they would want the car driver to behave—in such a circumstance. For example, in response to the green shared lane, one cycling driver stated, "(The) symbol makes me wonder (about) bicyclists; I'd proceed with caution." The sharrow, while still not popular among cycling drivers, was considered preferable to a no-treatment option for many of the cycling drivers: "(This) makes a *huge* difference to me...this actually says, 'Expect to see a cyclist coming down here...be aware.'"

These preferences for comfort result in a hierarchy of roadway designs: some are clearly low in the list for drivers and cyclists (sharrows and green shared lanes), and some are clearly preferable for drivers and cyclists (barrier-separated bike

[1] Tables A2 and A3 in Appendix A present the raw numbers corresponding to Figs. 2 and 3, respectively.
[2] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

Table 2
Survey population compared to bay area characteristics.

	Survey sub-sample (N = 265)%	Full survey sample (N = 463)%	Bay area population (N = 6,666,861)%
Age[a]			
18–24	5	6	9
25–34	33	36	15
35–44	14	18	15
45–54	25	21	15
55–64	19	16	12
65+	4	4	12
Sex[a]			
Male	47	45	50
Female	52	54	50
Race/Ethnicity[b]			
Caucasian or White	67	59	51
[*]Hispanic	3	5	23
African American or Black	5	5	7
Asian	9	15	25
Native American or Alaska Native	1	–	1
Native Hawaiian or Pacific Islander	–	1	1
Other	8	7	11
Two or more races	3	5	5
Decline to say	3	3	–
Annual household income[c]			
Less than $35,000	15	15	22
$35,000–$49,999	8	10	10
$50,000–$74,999	19	19	15
$75,000–$99,999	14	13	12
$100,000–$149,999	20	18	18
$150,000 or more	11	12	22
Decline to say	11	12	–
Children < age 18 in household[d]			
[#]Yes	19	22	30

[a] United States Census, 2011 Summary File 1, QT-P1 Age Groups and Sex.
[b] United States Census, 2011 Summary File 1, QT-P3 Race and Hispanic or Latino Origin.
[c] American Community Survey 2007–2011 5-year Estimates, B19001 Household Income in Past 12 Months.
[d] United States Census, 2011 Summary File 1, DP-1 Profile of General Population and Housing Characteristics.
[*] Hispanic counted separately from other races in Census, so total adds up to more than 100%.
[#] The survey asked about children under age 16, while the Census asks about children under age 18; while close, these results are not exactly comparable.

lanes, lanes on streets without parallel parking, green bike lanes). The complication seems to be what to do when there is not enough room for a separated facility. In that case, bicyclists prefer more treatment, rather than less, while drivers prefer the opposite.

The perceptions of comfort were also examined by gender, with the results following a similar pattern to those above. Female respondents were significantly less comfortable ($p \leqslant 0.001$) bicycling on any of the shared space designs, as well as driving on roadways with shared lane markings and the green shared lane. They were also significantly ($p \leqslant 0.01$) less comfortable driving on roadways with a striped or painted bicycle lane next to on-street parking.

4.3. Bike lane beliefs

To understand some of the positive and negative perceptions of bicycle facilities, respondents were also asked to rate their level of agreement or disagreement with several statements about striped bicycle lanes in particular. The percentage of respondents who agreed or strongly agreed with each of the statements is shown in Table 3. For most of these statements, there was no significant difference between groups according to bicycling frequency. Note that the trend is general agreement with the more positive aspects of bicycle lanes, and disagreement with the more negative aspects. For example, nearly 100% of respondents agree or strongly agree that bicycle lanes tell drivers to expect bicyclists on the roadway. Comments from the focus groups support this, for example, "Based on the bike lanes, I would expect (cyclists)." At least 85% of respondents also believe that bicycle lanes give bicyclists their own space. These two statements likely underlie some of the comfort ratings for bicycle facilities seen in Figs. 2 and 3.

At least 80% also agree that bicycle lanes make bicyclists more predictable on the roadway—a potential benefit for drivers (indeed, 83 and 86% of non- and potential cyclists, respectively, agreed with this statement) that runs counter to the idea that bicycle lanes benefit only bicyclists. The theme of predictability emerged multiple times in the focus groups, such as, "(a) striped bike lane delineates the space better and creates more responsibility and predictability for the driver and cyclist." This perceived benefit of bicycle lanes may help explain recent findings that drivers in the San Francisco East Bay and Los

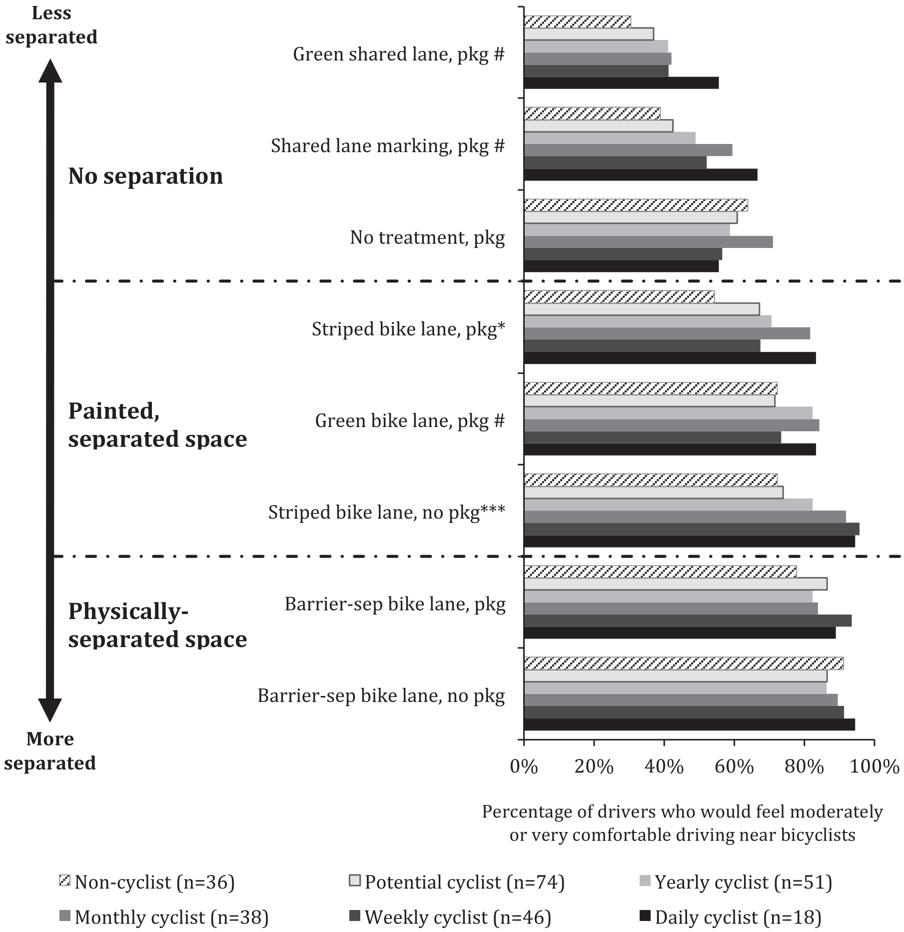

Fig. 2. How comfortable or uncomfortable would you feel driving a car in the presence of bicyclists on roadways with these bicycle facilities? (N = 263). Kruskal Wallis tests indicated significant correlation between cycling frequency and perceptions of comfort at the following levels: $^{\#} = p \leqslant 0.10$; $^{*} = p \leqslant 0.05$; $^{***} = p \leqslant 0.001$.

Angeles metropolitan area named bicycle lanes as a top requested traffic safety improvement along two major arterial roadways (Sanders et al., 2012; Sanders and Cooper, 2013).

The significant difference between cycling groups in terms of the belief that bicycle lanes increase the chance of being hit by a car door is likely influenced by experience. Despite the fact that the majority of the sample did not agree with this statement, evidence from the focus groups suggests that this fear may have played some role in the relatively low comfort ratings the striped bike lane received in comparison to other treatment options.

It is disconcerting that nearly 40% of non- and potential cyclists agree that bicycle lanes tell drivers that cyclists don't belong on non-bicycle routes, as this belief may diminish some of the perceived benefits of bicycle lanes by contributing to driver confusion and possibly frustration with cyclists—particularly in areas with limited bicycle facilities. However, there is no significant correlation between driving frequency and the belief that cyclists do not belong on non-cycling routes. This belief may therefore reflect ignorance of roadway rules in California (i.e., that bicyclists are allowed on all roadways except where expressly prohibited) and may also reflect the contrasting legitimacy that pavement markings give to bicyclists on roadways that were originally designed for automobiles rather than bicyclists. Future research should further investigate this finding.

The potential of bicycle lanes to communicate that bicyclists only belong on certain streets has long been used as an argument against bicycle lanes by vehicular cyclists, who fear that their roadway rights and freedom will be taken away if bicycle lanes proliferate (Forester, 2000). However, as seen in Fig. 3, the vast majority of cyclists of all types feel more comfortable with bicycle-specific facilities than without them, suggesting that avoiding the use of on-road bicycle treatments contradicts efforts to attract more bicycling. Instead, it may be critical to revise driver education and training to ensure understanding of roadway laws for multiple user groups. Another strategy would be to uniformly design certain roadway types with bicycle facilities and/or markings. In European cities with a high bicycling mode share

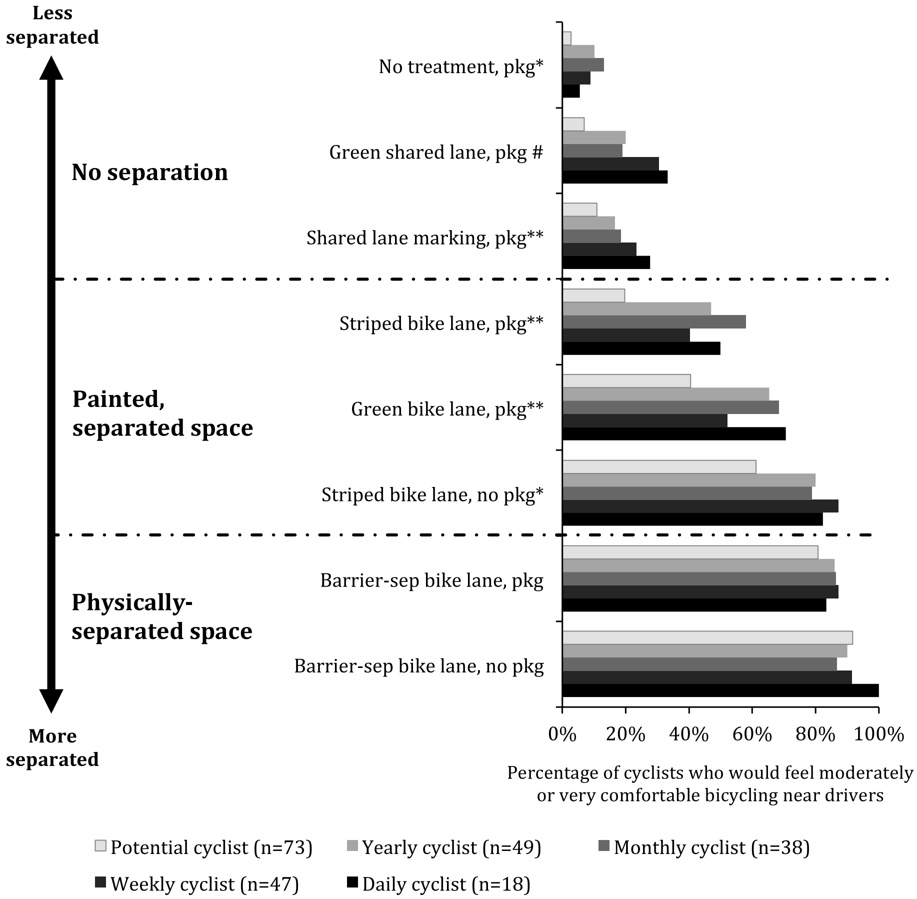

Fig. 3. How comfortable or uncomfortable would you feel bicycling in traffic on roadways with these bicycle facilities? (N = 225). (Non-cyclists who would not consider bicycling again did not rate designs for bicycling.) Kruskal Wallis tests indicated significant correlation between cycling frequency and perceptions of comfort at the following levels: # = $p \leqslant 0.10$, * = $p \leqslant 0.05$, ** = $p \leqslant 0.01$.

Table 3
Respondents believe bicycle lanes are beneficial, with few drawbacks (N = 263).

	Non-cyclists (n = 36)%	Potential cyclists (n = 73)%	Yearly cyclists (n = 51)%	Monthly cyclists (n = 37)%	Weekly cyclists (n = 48)%	Daily cyclists (n = 18)%
(+) Bicycle lanes...						
...tell drivers to expect bicyclists	89	96	90	97	96	89
...give cyclists their own space	86	89	92	95	96	89
...make cyclists more predictable on the roadway	83	86	75	81	85	88
...allow cyclists to ride at their own pace	75	68	73	75	75	67
(−) Bicycle lanes...						
...tell drivers that cyclists don't belong on non-bicycle routes*	36	40	24	19	31	22
...make it more difficult for cyclists to turn left	36	32	31	30	21	28
...increase the chance of being doored**	22	15	6	8	17	22
...encourage drivers to drive closer to cyclists	8	10	4	11	6	22
...unnecessarily restrict fast cyclists	9	3	4	0	4	6

Significant differences between non-cyclists, occasional cyclists, and regular cyclists at the following levels:
* $p \leqslant 0.05$.
** $p \leqslant 0.01$.

(e.g., Copenhagen, Denmark; Amsterdam, Netherlands; Paris, France), major roadways typically have some type of separated bicycle facility, while minor, residential roadways may have signage and markings or just general traffic calming. These findings provide a foundation for further research in this area.

5. Discussion & policy recommendations

The findings presented in this paper contribute knowledge about roadway design preferences among motorists driving near cyclists, and potential and current cyclists bicycling near motorists. The findings suggest several key takeaways for practice.

Takeaway for Practice 1: Regardless of bicycling experience, more drivers and cyclists reported feeling at least moderately comfortable on multi-lane streets with barrier-separated bicycle lanes than any other treatment. The barrier-separated lane without parking was slightly preferred to the barrier-separated lane next to on-street parking, but in both cases a large majority of the respondents indicated that they would feel at least moderately comfortable using the facility.

It is worth noting that there has been some concern that the increase in perceived safety from more protected facilities would lead to less careful behavior and therefore reduced actual safety for cyclists. While additional research would be beneficial, recent evidence from North America suggests that separated bike lanes are overall at least as safe as other facilities (Lusk et al., 2011; Harris et al., 2013; Zangenehpour et al., 2016). Moreover, separated bike lanes have been designed for decades in cities known for low rates of cycling injuries, such as Copenhagen and Amsterdam, and studies from these communities suggest that separated bike lanes contribute to safety when designed well (Schepers et al., 2011; Thomas and DeRobertis, 2013). Care should be taken to design separated bike lanes thoughtfully, including consideration of curb access for the mobility-challenged and improved safety through phase separation, clear sight lines, and intersection enhancements such as raised crossings. It also makes sense to accompany new facilities with public educational campaigns to teach and encourage expected behavior.

Policy recommendation: Prioritize separated bicycle lanes where feasible, taking care to address access, safety, and educational needs in the process.

Takeaway for Practice 2: Roadway designs with shared space (e.g., sharrows, a green shared lane, or no treatment) were relatively unpopular with both cyclists and drivers. Between the three shared-space options, drivers preferred no treatment over minimal treatment, which focus group findings suggested was at least partially based in a lack of understanding about how drivers and cyclists are expected to behave in the presence of shared space markings. In contrast, cyclists prefer some type of marking to none at all, but only a small portion reported that they would feel at least moderately comfortable in any of the shared spaces. Potential cyclists were especially averse to shared space. *Policy recommendations*: (a) Use shared space markings judiciously—and sparingly—on major roadways; (b) Educate all roadway users about expected behavior on or near bicycle facilities.

Takeaway for Practice 3: Perceptions of striped bicycle lanes—the most common on-road, marked bicycle facility in the U.S. (National Association of City Transportation Officials, 2011)—were mixed. While a large majority of the sample thought that bicycle lanes communicated that drivers should expect cyclists on the roadway and increased drivers' perceptions of predictability when driving near cyclists, there were some concerns that striped bicycle lanes communicated that drivers should not expect cyclists on non-bicycle routes, and that a striped bicycle lane in the "door zone" of a car may actually increase, rather than mitigate, traffic risk—although no research has indicated that this is the case. *Policy recommendations*: (a) Upgrade striped bicycle lanes to separated, buffered, or at least painted bicycle lanes where possible; (b) Educate all roadway users about rights to the roadway for all user groups.

Takeaway for Practice 4: Efforts to understand roadway design and route preferences should explore the needs of all roadway users in an effort to provide streets and networks that meet the needs of multiple modes. This study found an unexpected alignment in preferences with regard to separated spaces, but divergent preferences regarding shared space treatments. *Policy recommendation:* Examine the opinions and needs of all roadway user groups when designing/redesigning roadways and intersections where multi-modal travel is allowed.

6. Conclusion

This study is one of the first to examine motorists' design preferences regarding multi-modal roadways in a policy era focused on complete streets. The findings presented here suggest alignment between drivers and cyclists for roadway designs that can meet the needs of both user groups while sharing the road, with both groups preferring greater separation on multi-lane roadways. These findings also corroborate past research on bicyclists' preferences, and support U.S. federal policy encouraging more substantial accommodation for cyclists on roadways (FHWA, 2013, 2015).

Future studies on roadway design preferences could include a greater selection of design treatments, such as buffered bicycle lanes or grade-separated cycle tracks, and investigate comfort regarding intersection design. Additionally, these studies would benefit from considering the preferences of multiple user groups (e.g., pedestrians, bicyclists, transit users, and motorists) to provide opportunities for synergistic design that serves multiple groups. Research focusing on specific design treatments could also clarify their impact on drivers' and cyclists' beliefs about bicyclists' rights to the road. There is also a particular need for research examining the risk of injury from collisions or near misses sustained while bicycling in the "door zone" of the roadway, and how that risk is affected by bicycle lane treatments that allocate space for cyclists next to on street parking.

Acknowledgments

Thanks to the anonymous reviewers, as well as Elizabeth Deakin, Elizabeth Macdonald, Ian Carlton, Erick Guerra, Manish Shirgaokar, Allie Thomas, and Jake Wegmann for their feedback. In addition, thanks to the University of California Transportation Center, UC Berkeley Dean's Normative Time Fellowship, and the Eisenhower Transportation Program for supporting the research.

Appendix

See Tables A1–A3.

Table A1
Survey sample population characteristics (N = 463).

	Non-cyclists (n = 45)%	Potential cyclists (n = 145)%	Yearly cyclists (n = 100)%	Monthly cyclists (n = 71)%	Weekly cyclists (n = 76)%	Daily cyclists (n = 26)%	Total (N = 463)%
Age							
18–24	4	4	5	6	9	12	6
25–34	27	36	25	48	38	50	36
35–44	11	21	23	10	18	12	18
45–54	13	18	35	21	18	8	21
55–64	27	19	10	13	14	19	16
65–74	13	1	2	3	–	–	3
75+	4	1	–	–	–	–	1
	Kruskal Wallis significant ($p \leqslant 0.001$)						
Sex							
Male	29	35	54	59	43	62	45
Female	71	63	46	39	55	38	54
	Chi-square significant ($p \leqslant 0.001$)						
Race/Ethnicity							
White, non-Hispanic	49	54	60	62	70	65	59
Hispanic	7	3	5	4	7	–	5
African American or Black	9	6	3	4	4	–	5
Asian	13	21	14	13	5	23	15
Other races	11	8	7	13	8	4	9
Two or more races	4	5	7	1	4	4	5
Decline to say	7	2	4	3	3	4	3
	Fisher's exact not significant						
Driving frequency[a]							
Never	–	–	3	3	7	–	2
Less than once per week	7	2	4	8	13	38	8
One to three days per week	22	26	15	18	38	54	27
Four or more days per week	71	71	78	70	42	8	68
	Kruskal Wallis significant ($p \leqslant 0.0001$)						
Annual household income							
Less than $35,000	20	14	9	17	16	19	15
$35,000–$49,999	11	12	8	10	9	4	10
$50,000–$74,999	22	18	22	15	22	12	19
$75,000–$99,999	13	14	12	15	13	12	13
$100,000–$149,999	13	14	28	14	13	38	18
$150,000 or more	7	13	13	14	13	8	12
Decline to say	13	14	8	14	13	8	12
	Kruskal Wallis not significant						
Children < Age 16 in household							
Yes	11	23	32	20	14	15	21
	Chi-square significant ($p \leqslant 0.05$)						

[a] "Driving frequency" refers to how many times per week the respondent drives a car.

Table A2
Percentage of respondents feeling at least moderately comfortable driving near cyclists on each roadway (N = 263).

	Non-cyclists (n = 36)%	Potential cyclists (n = 74)%	Yearly cyclists (n = 51)%	Monthly cyclists (n = 38)%	Weekly cyclists (n = 46)%	Daily cyclists (n = 18)%
While driving near bicyclists						
Barrier-separated bike lane, no pkg	91	86	86	89	91	94
Barrier-separated bike lane, parking	78	86	82	84	93	89
Striped bike lane, no parking***	72	74	82	92	96	94
Green bike lane, parking#	72	72	82	84	73	83
Striped bike lane, parking*	54	76	71	82	67	83
Shared lane marking, parking#	39	42	49	59	52	67
Green shared lane, parking#	31	37	41	42	41	56
No treatment	64	61	59	71	57	56

Kruskal Wallis tests indicated significant correlation between cycling frequency and perceptions of comfort at the following levels:
$p \leqslant 0.10$.
* $p \leqslant 0.05$.
*** $p \leqslant 0.001$.

Table A3
Percentage of respondents feeling at least moderately comfortable bicycling near drivers on each roadway (N = 225).

	Non-cyclists[a] (n = 36)%	Potential cyclists (n = 73)%	Yearly cyclists (n = 49)%	Monthly cyclists (n = 38)%	Weekly cyclists (n = 47)%	Daily cyclists (n = 18)%
While bicycling near motorists						
Barrier-separated bike lane, no pkg	n/a	92	90	87	91	100
Barrier-separated bike lane, parking	n/a	81	86	86	87	83
Striped bike lane, no parking*	n/a	61	80	79	87	82
Green bike lane, parking**	n/a	41	65	68	52	71
Striped bike lane, parking**	n/a	20	47	58	40	50
Shared lane marking, parking**	n/a	11	17	18	23	28
Green shared lane, parking#	n/a	7	20	19	30	33
No treatment*	n/a	3	10	13	9	6

Kruskal Wallis tests indicated significant correlation between cycling frequency and perceptions of comfort at the following levels:
$p \leqslant 0.10$.
* $p \leqslant 0.05$.
** $p \leqslant 0.01$.
[a] Non-cyclists who would not consider bicycling again did not rate designs for bicycling.

References

American Community Survey, 2006–2010. Sex of Workers by Means of Transportation. American Community Survey.
Andersen, M., 2013. Selling biking: bike images that people like. Opinions Held by the "Swing Voters" of Bicycling (Retrieved April 12, 2015).
Author, 2013. Dissecting Perceived Traffic Risk as a Barrier to Adult Bicycling. Transportation Research Board, Washington, DC.
Broach, J., Dill, J., et al, 2012. Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transp. Res. Part A 46, 1730–1740.
Caulfield, B., Brick, E., et al, 2012. Determining bicycle infrastructure preferences – a case study of Dublin. Transp. Res. Part D (17), 413–417.
Dill, J., McNeil, N., 2013. Four types of cyclists? Examination of typology for better understanding of bicycling behavior and potential. Transp. Res. Rec. 2387, 129–138.
Dill, J., Voros, J., 2007. Factors affecting bicycling demand: initial survey findings from the Portland, Oregon, region. Transport. Res. Rec.: J. Transport. Res. Board (2031), 9–17.
FHWA, 2004. National Bicycling and Walking Study: Ten Year Status Report by the U.S. Department of Transportation. U.S. Department of Transportation, Washington, D.C., 2009.
FHWA, 2013. Guidance: Bicycle and Pedestrian Facility Design Flexibility. Planning Environment and Realty, Infrastructure, Operations and Safety. Federal Highway Administration, Washington, D.C..
FHWA, 2015. Separated Bike Lane Planning and Design Guide. Federal Highway Administration, Washington, DC.
Flusche, D., 2010. Highlights from the 2009 National Household Travel Survey. League of American Bicyclists, Washington, DC.
Flusche, D., 2012. Bicycle Commuting Data Retrieved June 12, 2013, from http://www.bikeleague.org/news/acs2010.php.

Flusche, D., 2000. The Need to Change Federal Policy and Practice Regarding Bicycle Transportation Retrieved July 1, 2013, from http://www.johnforester.com/Articles/Government/fedpol01.htm.
Harris, M.A., Reynolds, C., et al, 2013. Comparing the effects of infrastructure on bicycling injury at intersections and non-intersections using a case-crossover design. Injury Prevent. http://dx.doi.org/10.1136/injuryprev-2012-040561 (Published online first: February 14, 2013).
Haworth, N.L., Schramm, A.J., 2011. How do level of experience, purpose for riding, and preference for facilities affect location of riding? Study of adult bicycle riders in Queensland, Australia. Transp. Res. Rec. 2247, 17–23.
Lusk, A., Furth, P., et al, 2011. Risk of injury for bicycling on cycle tracks versus in the street. Injury Prevent. http://dx.doi.org/10.1136/ip.2010.028696 (Published online first: February 9, 2011).
Marshall, W.E., Garrick, N.W., 2011. Evidence on why bike-friendly cities are safer for all road users. Environ. Pract. 13 (1), 16–27.
McNeil, N., Monsere, C., et al, 2015. The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. Transportation Research Board, Washington, DC.
Monsere, C., Dill, J., et al, 2014. Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S. National Institute for Transportation and Communities, Portland, OR.
National Association of City Transportation Officials, 2011. Urban Bikeway Design Guide. National Association of City Transportation Officials, New York, NY, p. 1.
National Complete Streets Coalition, 2014. Policy Atlas Retrieved May 5, 2015, from http://www.smartgrowthamerica.org/complete-streets/changing-policy/complete-streets-atlas.
Parkin, J., Wardman, M., et al, 2007. Models of perceived cycling risk and route acceptability. Accid. Anal. Prev. 39, 364–371.
Pucher, J., Buehler, R., et al, 2011. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. Transp. Res. Part A 45, 451–475.
Sanders, R., Griffin, A., et al, 2012. The Effects of Transportation Corridor Features on Driver and Pedestrian Behavior and on Community Vitality: Final Study Report. California Department of Transportation, Berkeley, CA.
Sanders, R.L., Cooper, J.F., 2013. Do all roadway users want the same things? Results from a roadway design survey of pedestrians, drivers, bicyclists, and transit users in the bay area. Transp. Res. Rec. 2393, 155–163.
Schepers, J., Kroeze, P., et al, 2011. Road factors and bicycle-motor vehicle crashes at unsignalized priority intersections. Accid. Anal. Prev. 43, 853–861.
Sener, I.N., Eluru, N., et al, 2009. Who are bicyclists? Why and how much are they bicycling? Transp. Res. Rec. (2134), 63–72
Thomas, B., DeRobertis, M., 2013. The safety of urban cycle tracks: a review of the literature. Accid. Anal. Prev. 52, 219–227.
Tilahun, N.Y., Levinson, D.M., et al, 2007. Trails, lanes, or traffic: valuing bicycle facilities with an adaptive stated preference survey. Transp. Res. Part A 41, 287–301.
Winters, M., Teschke, K., 2010. Route preferences among adults in the near market for bicycling: findings of the Cycling in Cities study. Am. J. Health Promot. (1), 40–47
Winters, M., Teschke, K., et al, 2010. How far out of the way will we travel? Built environment influences on route selection for bicycle and car travel. Transp. Res. Rec. 2190, 1–10.
Zangenehpour, S., Strauss, J., et al, 2016. Are signalized intersections with cycle tracks safer? A case-control study based on automated surrogate safety analysis using video data. Accid. Anal. Prev. 86, 161–172.