Do People's Perceptions of Neighborhood Bikeability Match "Reality"?

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Submitted for Presentation at the 94th Annual Meeting of the Transportation Research Board

August 1, 2014

Word Count: 5263 words + 9 Tables & Figures = 7513 total

ABSTRACT

Do people perceive the built environment the same as we objectively measure it? If not, what are the relative roles of the objective versus the perceived environment on bicycling behavior? This study, based on data from Portland Oregon, explored the match or mismatch between the objective and perceived bicycling environment, and how it affects people's bicycling behavior. The descriptive analysis indicated a fair agreement between perceived and objective measures. Older adults, women having children, less-educated and lower-income persons, and those who bicycle less tended to perceive their high-bikeable environment (measured objectively) as low-bikeable. In addition to the socio-demographics, this study also found social environment can play a role in the relationship between objective and perceived environment. Finally, results of this study indicated that actual and perceived built-environment both are associated with the bicycling behavior, particularly for utilitarian bicycling. For recreational bicycling, the objective environment attributes measured in this study are not significant factors, while the perceptions do matter.

Key words: bicycling; built environment; perceived measure; objective measure

INTRODUCTION

Studies linking the built environment to travel behavior or physical activity generally use two categories of built environment measures: perceived (self-reported) and objective [1, 2]. Perceived measures are generally obtained from interviews or self-administered questionnaires, objective measures are typically derived from systematic observations, audits, or GIS-based measures relying on existing spatial data (e.g. street network, land-use data). Though many studies use objective and perceived measures interchangeably, the mismatch between the perceived and objective environment and their different effects on travel behavior and physical activity have recently been recognized [3-14].

The mismatch between the perceived and objective environment is one of the reasons leading to mixed findings from the travel behavior-built environment studies [5, 15, 16]. This is also one of the reasons that not all people, even in “pedestrian friendly” and “bike friendly” environments, choose not to walk and bicycle [5, 16]. Improved understanding of the relationships between the objective and perceived environment on travel behavior could be important for understanding the mechanism underlying the built environment- behavior relationship and for identifying potential interventions [3, 17, 18]. However, few empirical studies have explored the magnitude and effects of the mismatch on active travel behavior, particularly bicycling behavior. Further, there is little known on the factors contributing to the mismatch between the objective and perceived environment.

This study aims to (1) explore the mismatch between the perceived and objective bicycling environment; (2) investigate the characteristics of the people whose perceptions do not match the objectively-measured environment, in particular is the question of why people living in presumably highly-bikeable environments perceive it as a low-bikeable environment. We do so using survey data from a large random sample survey of adults in the Portland, OR metropolitan area.

PREVIOUS RESEARCH

Recent studies have examined the concordance between the perceived and objectively-measured environment, comparing their different roles on physical activity. Almost all of these studies are published in health journals. Though the initial purpose of these studies is often to investigate the validity of survey instruments, the researchers have realized that the difference between self-reported perceptions and objective measures of the environment can be substantive, and this difference is due to many other factors, in addition to the survey design or audit methods. In these studies, the perceived environment is usually derived from self-reported surveys, while GIS databases and audit tools are used to measure the objective environment. Most of these studies use cross-sectional data with only one exception [7].

Most of these studies find that agreement or concordance between objective and perceived (also referred to as “subjective”) built environment is poor to moderate based on kappa statistics. Kirtland et al. [8] conducted a telephone survey to investigate walking environments in Sumter County, South Carolina. Using kappa statistics they found a fair to low agreement between subjective and objective measures. McCormack et al. [9] compared the perceived and objectively measured distance to several destinations and found that distances to most destinations close to home were overestimated, whereas distances to those farther away were underestimated. They also concluded that concordance between subjective and objective measures was low to moderate. McGinn et al. [10] used a telephone survey (n=1,270) in Forsyth County, NC and Jackson, MS, and also found a poor agreement between perceived and objective measures. Ball et al. [11] investigated the concordance between self-reported and objective (i.e. audit) measures of physical activity facilities based on a self-report surveys of 1,540 women from 45 neighborhoods in Melbourne, Australia, and they found relatively poor agreement. Lackey and Kaczynski [12] examined how the individual, neighborhood, and park-related variables influenced the agreement between self-reported and objectively measured distance to parks, and they also found that agreement was poor but agreement was higher in certain subgroups. Prins et al. [13] explored the degree of agreement between objective and perceived availability of physical activity facilities in neighborhood as well as the relative effect of perceived and objective environment on adolescent engagement in sports activities and walking and cycling in leisure time. They found that agreement was low to moderate based on the kappa values.

Several of these studies further explored the factors contributing to the mismatch, and most concluded that levels of physical activity, socio-demographic characteristics of respondents, and quantity and quality of amenities in the built environment can influence the relationship between perceptions and objective reality. Kirtland et al. [8] found that those engaging in physical activity tended to have higher agreement than inactive individuals. McCormack et al. [9] explored the moderation effect of age, gender, and walking behavior on the agreement between objective and perceived distance, and found the following: men tended to overestimate distance to the nearest supermarket than women; those who walked for utilitarian purposes for more than 25 minutes per week overestimated distance to the nearest supermarket compared with those walking less than 25 minutes per week; and those who walked for recreation for less than 130 minutes per week overestimated distance to the closest shop to a larger extent than those walking more than 130 minutes per week. Ball et al. [11] found that mismatch between perceived and objectively measured environments was more frequent among women who were younger, older, lower-income, less active, using fewer facilities, and living in the neighborhood for less than 2 years. Lackey and Kaczynski [12] found that respondents with the following characteristics were more likely to achieve a match: reported participating in at least some park-based physical activity; a greater number of parks nearby; closest park had more features; and closest park contained a playground or wooded area. Gebel et al. [6] identified that adults with lower educational attainment and lower income, and those who were less physically active or overweight were more likely to perceive their high walkable neighborhood as low walkable. McGinn et al. [10] also investigated whether the agreement varied between active and inactive people, but found no significant difference.

METHODOLOGY

The data were obtained through a random phone survey of adults in the Portland, Oregon region. The sample included both land-line and mobile phone numbers and was conducted July 19 through August 10, 2011. A total of 902 interviews were completed. Of those, 130 (14 percent) were completed on mobile phones. The mobile phone sample was used to help reduce sampling bias, particularly among younger adults. The overall response rate was 20%. More details about the survey are available in Dill and McNeil [19].

To analyze the mismatch between objective and perceived bikeability, we first need to categorize each participant into distinct groups with different combinations of objective and perceived bikeability. To do so, we followed a method used by Van Acker et al. [5] that combined factor and cluster analysis to identify different land-use and perception clusters. The task of factor analysis is to extract underlying dimensions of objective and perceived bikeability from a list of observed indicators. The task of a cluster analysis is to assign each participant to clusters that are relatively homogeneous within and relatively heterogeneous in relation to other clusters. Cluster analysis has been widely used in social science [20].

Our measures of bikeability are based upon the growing literature linking the bicycle infrastructure, the built environment and bicycling. A number of studies have found that striped bicycle lanes [21-23], off-street bike paths [24-26], bicycle boulevards [27], and low traffic streets are associated with more bicycling [28, 29]. In addition to the bicycle infrastructure, more and more studies find that other aspects of the built environment may support bicycling. Street connectivity, for example, is positively associated with odds of bicycling for both utilitarian and recreation purpose [30, 31]. Also, accessibility is consistently found to be associated with both bicycling propensity and bicycling frequency [25, 32-34].

For perception of bikeability, we included the following indicators in the factor analysis: (1) “There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to”; (2) “There are bike lanes that are easy to get to”; (3) “There are quiet streets, without bike lanes, that are easy to get to on a bike”; (4) “There is so much traffic along nearby streets that it would make it difficult or unpleasant to bike”; (5) “Many of the places I need to get to regularly are within biking distance of my home”; (6) “How satisfied are you with your neighborhood design in terms of bike safety”. The first five items are scored using a five-point Likert scale from strongly disagree to strongly agree, the last item is scored using a five-point Likert scale from very dissatisfied to very satisfied.

Corresponding to these perception indicators, we created different objective measures to line up with perceived measures. For example, several objective measures, including miles of off-street bike paths within 1/8-, 1/4- 1/2- and 1-mile circular and network buffers and distance to the nearest off-street bike path, were created to match with perceived off-street path. After a series of comparisons of different sets of variables, we finally decided to use the following objective indicators to measure objective bikeability because they have better associations with the perception measures: miles of off-street bike path within 1-mile network buffer, miles of bike lanes within 1-mile network buffer, miles of minor streets within 1-mile network buffer, number of common destinations (e.g. convenience stores, grocery stores, restaurants & bars, beauty salons, postal service, etc.) within 1-mile network buffer, street connectivity (defined as number of street intersections with three or more valences divided by total number of intersections) within 1-mile network buffer, and hilliness (defined as ratio of area with a slope equal or higher than 25 percent) within 1-mile network buffer. These objective measures have been proved to be associated with bicycling behavior in previous research. Objective environmental data, such as street network and land use information, are from the Regional Land Information System (RLIS) from Portland Metro, the region’s transportation and land use planning agency.

Even though we put much effort in trying to match the perceived and objective measures, they cannot perfectly line up because of data limitations. For example, we do not have good objective measures that correspond to the perceptions of traffic and perceptions of neighborhood design for bicycling safety. Instead, we use street connectivity and miles of minor streets as the approximate objective measures. However, this limitation is not expected to materially affect the analysis and results.

The composite measures based on factor analysis help to reduce the mismatching errors from individual variables.

Through the factor analysis based on the six indicators of perceived bikeability, one principal factor was extracted, and it explained 43% of the variance (see Table 1). By analyzing its loadings on each indicator, we found this factor represents an overall positive perception of the bicycling environment. For example, this factor has positive loadings on perceptions of presence of bike lane, bike path, and quiet streets, and also on satisfaction of safety design and destination accessibility, but has negative loadings on perception of traffic which is unpleasant to bicycle. Through the factor analysis (Varimax rotation method was used) based on the seven indicators of objective bikeability, two principal factors were extracted for objective bikeability from the seven objective indicators, which explained 65% of the variance (see Table 2). The two extracted factors represent two underlying dimensions of bicycling environment: (1) land use and design: accessibility, street network, quiet streets, and (2) dedicated bicycling infrastructure: bicycle lane and paths.

Table 1 Factor analysis for perceived bikeability

	Factor 1
There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to.	.751
There are bike lanes that are easy to get to.	.781
There are quiet streets, without bike lanes, that are easy to get to on a bike.	.685
There is so much traffic along nearby streets that it would make it difficult or unpleasant to bike.	-.604
How satisfied are you with your neighborhood design in terms of bike safety?	.701
Many of the places I need to get to regularly are within biking distance of my home.	.311

Table 2 Factor analysis for objective bikeability

	Factor 1	Factor 2
Total number of destinations within 1-mile network buffer	.650	.482
Number of street intersections with three or more valences divided by total number of intersections within 1-mile network buffer	.863	.112
Ratio of area with a slope equal or higher than 25 percent within 1-mile network buffer	-.408	-.405
Miles of minor street within 1-mile network buffer	.893	.114
Miles of bike boulevard within 1-mile network buffer	.887	-.169
Miles of bike lane within 1-mile network buffer	.100	.839
Miles of off-street bike path within 1-mile network buffer	-.057	.665

Two cluster analyses were then conducted based on the extracted factors from perceived and objective indicators. The hierarchical cluster with Wald's method was used. This procedure aims to assign participants who shared similar characteristics in perception or who lived in similar bicycling environments to a cluster. The cluster analysis based on the perception factor lead to the identification of two groups. The two groups have a clear contrast in perceptions of bicycling environment (see Table 3). Group 1 has significantly higher perceptions of the bicycling environment than Group 2. We, therefore, named Group 1 as high perception and Group 2 as low perception.

By the same method, three distinct groups were identified using cluster analysis based on the two factors from objective environment indicators. Also, the three groups suggest distinct characteristics in the bicycling environment (see Table 4). To clarify their cluster-specific differentiation in terms of objective bikeability, we gave the three group names:

- High objective bikeability (Group 1): high percentage of connected street, good accessibility, high density of low-traffic street, some bike lanes and paths, relatively high number of bicycle boulevards, most flat area
- Moderate objective bikeability (Group 2): higher density of bike lanes and paths, moderate accessibility, moderate density of low-traffic street, relatively lower percentage of connected street, most flat area
- Low objective bikeability (Group 3): low level of connected streets, accessibility, low-traffic streets, bike lanes, and paths, many hilly area

Even though Group 1 was labeled more bikeable than Group 2, the two groups may represent two different types of a "good" environment for bicycling. The environment of Group 1 is better in terms of bicycling accessibility and interaction with traffic, while the environment of Group 2 have more dedicated bicycling infrastructure. It is possible that some bicyclists prefer the environment of Group 2 than that of Group 1. It is also possible that one type is superior to the other one in terms of different bicycling purposes. Based on these data, we cannot identify a group that combines the merits of group 1 and group 2. It seems there is a difference between the underlying built environment and bicycling infrastructure. We chose to label Group 1 as "high" in this analysis because our previous work with a different data set found that the physical characteristics found in Group 1 had stronger associations with neighborhood bicycling than did the presence of striped bike lanes [35]. That study also found that, it is useful to look at bicycling infrastructure separately from other built environmental characteristics.

Table 3 Different perceptions between Group 1 (high perception) and Group 2 (low perception)

		n	Mean	P-value
There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to.	High Perc.	327	3.50	.000
	Low Perc.	363	1.93	
There are bike lanes that are easy to get to.	High Perc.	327	3.56	.000
	Low Perc.	363	1.97	
There are quiet streets, without bike lanes, that are easy to get to on a bike.	High Perc.	327	3.88	.000
	Low Perc.	363	3.00	
There is so much traffic along the street I live on that it would make it difficult or unpleasant to bike.	High Perc.	327	1.46	.000
	Low Perc.	362	2.00	
There is so much traffic along nearby streets that it would make it difficult or unpleasant to bike.	High Perc.	327	1.82	.000
	Low Perc.	363	2.93	
How satisfied are you with your neighborhood design in terms of bike safety?	High Perc.	327	4.33	.000
	Low Perc.	363	2.90	
Many of the places I need to get to regularly are within biking distance of my home.	High Perc.	327	3.56	.000
	Low Perc.	363	2.71	

Table 4 Different built environmental attributes among Group 1 (high objective bikeability), Group2 (moderate objective bikeability) and Group3 (low objective bikeability)

		n	Mean	P-value
Ratio of connected street within 1-mile network buffer	High Obj.	174	93%	.000
	Moderate Obj.	191	76%	
	Low Obj.	513	71%	
Total number of destinations within 1-mile network buffer	High Obj.	174	156	.000
	Moderate Obj.	191	105	
	Low Obj.	513	28	
Ratio of area with a slope equal or greater than 25 percent within 1-mile network buffer	High Obj.	174	7%	.000
	Moderate Obj.	191	9%	
	Low Obj.	513	26%	
Miles of minor street within 1-mile network buffer	High Obj.	174	42.19	.000
	Moderate Obj.	191	23.62	
	Low Obj.	513	17.18	
Miles of bike boulevard within 1-mile network buffer	High Obj.	174	2.43	.000
	Moderate Obj.	191	.12	
	Low Obj.	513	.01	
Miles of bike lane within 1-mile network buffer	High Obj.	174	2.19	.000
	Moderate Obj.	191	4.36	
	Low Obj.	513	1.96	
Miles of off-street bike path within 1-mile network buffer	High Obj.	174	.23	.000
	Moderate Obj.	191	1.13	
	Low Obj.	513	.19	

RESULTS

To explore the relationship between perceived and objective bikeability, we first conducted an ANOVA analysis to test the difference in perceptions among the three objective groups. The results suggested that respondents of the three groups have distinct perceptions of the bicycling environment (see Table 5). In particular, respondents of Group 1 (high objective bikeability) had the highest perceptions in all aspects of bicycling environment except perceptions of off-street bike trails/paths. Respondents of Group 2 (moderate objective bikeability) perceived highest in off-street bike trails/paths, had relatively higher perceptions in bicycle lane, neighborhood design for bike safety, accessibility, and overall neighborhood environment than Group 3 (low objective bikeability). Those in Group 3 had the lowest perceptions of the bicycling environment. This result indicates that, in general, there is consistency between objective and perceived bikeability. Residents had higher perceptions in an environment with bicycling friendly design (low-traffic streets, connected streets, accessibility) and bicycling infrastructure than in an environment without these features. Further, perceptions are higher in bicycling friendly environment (low-traffic, connected street, accessibility) with relatively few bicycling infrastructure than in an environment with bike lanes and paths, but without other bicycling friendly design features.

Table 5 Comparison of perceptions among the three groups of objective bikeability

Perceptions of bicycling environment	**Objective bikeability**	**n**	**Mean***	**P-value**
There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to.	Group 1	132	2.63	0.000
	Group 2	144	3.06	
	Group 3	411	2.58	
There are bike lanes that are easy to get to.	Group 1	134	3.16	0.000
	Group 2	146	2.91	
	Group 3	414	2.52	
There are quiet streets, without bike lanes, that are easy to get to on a bike.	Group 1	135	3.74	0.000
	Group 2	145	3.32	
	Group 3	414	3.36	
There is so much traffic along nearby streets that it would make it difficult or unpleasant to bike.	Group 1	135	2.17	0.009
	Group 2	146	2.57	
	Group 3	414	2.43	
How satisfied are you with your neighborhood design in terms of bike safety?	Group 1	133	3.92	0.002
	Group 2	146	3.58	
	Group 3	413	3.47	
Many of the places I need to get to regularly are within biking distance of my home.	Group 1	135	3.74	0.000
	Group 2	144	3.26	
	Group 3	415	2.86	
Overall perception of bikeability (Factor score of above perception indicators)	Group 1	128	0.39	0.000
	Group 2	141	0.08	
	Group 3	406	-0.14	

*Scale for individual measures is 1-5, 1=strongly disagree, 5=strongly agree.

However, a further disaggregate exploration of different groups of participants reveals that not all residents who live in high bikeable neighborhood perceive it as high, nor do all the residents living in low bikeable neighborhood perceive it as low (see Table 6). About 47% of the participants perceived their

environment as the same level with the objective measure of the bikeable environment, while about 7% of the participants perceived their relatively good cycling environment as bad and about 25% of the participants perceived their bad cycling environment as good. In addition, about 10% of the participants perceived the moderate bikeability environment as high, while about 11% of the participants perceived it as low. Again, the moderate bikeability group defined in this study could also be a good cycling environment for some people. Therefore, it is more difficult to clearly define a “match” and “mismatch” in this environment.

Table 6 Match and mismatch between perceived and objective bikeability

		Perception of Bicycling Environment		Total
		High	Low	
Objectively-Measured Bicycling Environment	High	83	46	129
		12%	7%	19%
	Moderate	70	71	141
		10%	11%	21%
	Low	170	236	406
		25%	35%	60%
Total		323	353	676
		48%	52%	100%

Mismatch and Bicycling Behavior

The average number of days that the respondents bicycled for different purposes in the past month was used to compare the bicycling behavior among the match and mismatch groups (Table 7). It is evident that, for overall and utilitarian bicycling, the bicycling frequency goes down as the objective bicycling environment becomes worse. It is interesting to note that bicycling frequency for recreational purposes does not vary significantly among different levels of the objective environment. Moreover, persons with more positive perceptions of the environment generally bicycled more than those with low perceptions no matter what actual environment where they lived. This is true for both utilitarian and recreational bicycling.

The relative effects of the objective and perceived environment on bicycling behavior vary among different bicycling purpose (Table 7). For bicycling for daily errands, the objective environment plays a strong role in determining the frequency of the bicycling trips. Those who have high perceptions but live in moderate and low level of bikeability environment bicycle less often for daily errands than those who have low perceptions but live in high bikeability environments. For commuting, those live in high bikeability environments biked more often to work than those lived in moderate and low bikeability environment. The exception is the group living in moderate bikeability environments with high perceptions. They had the same bicycling frequency with the group that lived in high bikeability but have low perceptions. By contrast, those who live in moderate bikeability environments and have low perceptions and those live in low bikeability environments have much lower bicycling frequency, less than one day per month. This implies that objective bikeability is very important for commuting by bicycle, and strong perceptions are needed to bicycle in moderate bikeability environments. For recreational bicycling, the variations of bicycling frequency among different bikeability environments are not significant, while the perceptions do matter in affecting bicycling frequency for recreational purpose. It is also worth noting that the effects of perceptions on recreational bicycling are only significant for the low objective bikeability group. In summary, for utilitarian bicycling, both objective and perceived environment matter, while for recreational bicycling, the perceptions may play more important role than objective environment.

Table 7 Comparisons of bicycling frequency among different groups

	mean	mean	mean	p-value
Overall				
HO vs. MO vs. LO	**8.7**	**5.2**	**4.3**	**0.00**
HP vs. LP	**6.6**	**4.4**		**0.00**
HOHP vs. HOLP	**10.4**	**6.0**		**0.02**
MOHP vs. MOLP	6.5	4.3		0.12
LOHP vs. LOLP	4.7	4.1		0.41
Commuting				
HO vs. MO vs. LO	**2.1**	**0.7**	**0.4**	**0.00**
HP vs. LP	**1.3**	**0.6**		**0.03**
HOHP vs. HOLP	3.0	1.7		0.24
MOHP vs. MOLP	**1.7**	**0.0**		**0.02**
LOHP vs. LOLP	0.3	0.6		0.31
Errands				
HO vs. MO vs. LO	**4.2**	**1.4**	**1.4**	**0.00**
HP vs. LP	**3.0**	**1.7**		**0.00**
HOHP vs. HOLP	**6.0**	**3.2**		**0.05**
MOHP vs. MOLP	2.2	1.3		0.29
LOHP vs. LOLP	1.8	1.5		0.52
Recreation				
HO vs. MO vs. LO	3.9	4.2	3.1	0.10
HP vs. LP	**4.1**	**2.9**		**0.01**
HOHP vs. HOLP	4.4	3.2		0.29
MOHP vs. MOLP	4.8	3.9		0.50
LOHP vs. LOLP	**3.7**	**2.6**		**0.04**

Note: HO=High Objective Environment; MO=Moderate Objective Environment; LO=Low Objective Environment; HP=High Perceptions; LP=Low Perceptions.
*p-value is derived from ANOVA tests.

Mismatch and Socio-demographics, Attitudes, Social Environment and Neighborhood Safety

A mix of individual and societal factors likely contribute to the mismatch between the objective and perceived environment. The social-demographic attributes of participants, their attitudes, and the social environment within each match and mismatch category (Table 8) indicate that older adults, women, less-educated and lower-income persons, and those who do not have children tend to perceive high-bikeable environments as low, while young adults, men, higher-income persons and those with children are more likely to perceive low-bikeable environments as high. In contrast to previous studies [6, 11], this study did not find significant difference in respondents' health condition and years they lived in current neighborhood between matched and mismatched groups.

Through comparing the means, we found that people who like biking and transit are more likely to perceive high-bikeable environments as high, whereas those who like driving and walking tend to perceive high-bikeable environments as low. Also, a supportive social environment helps people to have better perceptions of the bicycling environment. Finally, those who feel high crime rate in neighborhood tend to perceive high-bikeable environments as low.

Table 8 Socio-demographics of participants in matched and mismatched groups

	High Bikeability		Moderate Bikeability		Low Bikeability	
	High Perc.	Low Perc.	High Perc.	Low Perc.	High Perc.	Low Perc.
Socio-demographics						
% Female	54%	65%	53%	65%	56%	59%
Age	47.4	53.0**	50.9	50.8	49.9	54.7***
Children in household	46%	28%*	33%	37%	40%	29%**
Education	6.2	5.8	5.3	5.2	5.8	5.9
Income	4.5	2.8***	3.8	3.5	4.6	4.6
Self-reported health condition	3.7	3.5	3.5	3.3	3.7	3.8
Years living in current home	13.6	13.2	14.5	14.6	14.9	14.7
Travel attitudes						
Pro-bike	0.77	0.22***	0.16	-0.03	0.42	-0.08***
Pro-transit	0.20	0.03	-0.04	0.06	-0.01	-0.07
Pro-walk	0.33	0.36	0.13	-0.05	-0.01	0.01
Pro-car	-0.3	-0.32	-0.01	-0.12	0.05	0.26
Negative Travel	-0.14	0.06	-0.01	0.06	-0.16	0.07**
Social environment						
Social norms	3.4	2.95**	2.69	2.47	2.75	2.36***
Neighborhood safety						
There is a high crime rate in my neighborhood	1.59	1.87*	1.75	2.17**	1.41	1.33

*, ** and *** denote the value is different from the value on the left at 10%, 5%, and 1% level respectively

Regression Analysis

People who live in a high bikeable neighborhood, but who perceive it as low bikeable, are of particular interest, because they are the likely targets of intervention programs. To identify the characteristics of this group, a binary logistic model was conducted comparing them to people living in a high bikeable neighborhood with high perceptions. The model captures different aspects of factors contributing to the mismatch, including residents' socio-demographics, their attitudes towards transportation, the social environment, and their bicycling behavior. Table 9 presents the model, which overall explains about 25% of the variation of the dependent variable.

The model suggests that women with children are one times more likely to perceive their high bikeable neighborhoods as low bikeable, comparing with the men without children. Compared with people aged 18 to 34, middle aged (35-54) people are less likely to hold low perceptions in high bikeable neighborhoods; by contrast, older people (55 and over) are nearly three times more likely to perceive high bikeable environment as low. Those without a college degree are 68% more likely to perceive a high bikeable environment as low. Those with lower household incomes (less than $50,000 per year) are nearly three times more likely to perceive high bikeable environment as low than those with relatively high income (equal or above $50,000 per year). In addition, those who reported good health condition and live in the neighborhood for a longer time are less likely to perceive high bikeable environments as low.

As for the attitudinal factors, residents who like walking are less likely to perceive their high bikeable neighborhoods as low, while those who dislike travel are more likely to have a mismatch. The social environment does play a role in the relationship between objective and perceived environment. A supportive social environment for bicycling helps to reduce the mismatch, while high crime rates in neighborhood are much more likely to induce the mismatch. Finally, as expected, frequent bicyclists are less likely to perceive high bikeable environments as low compared with occasional bicyclists and non-bicyclists.

In summary, lower socioeconomic status, as measured in educational attainment and household income, women having children in the household, older adults, having bad health condition, new movers into the neighborhood, families with high levels of car ownership, having negative attitudes towards bicycling and walking, having low levels of bicycling, unfavorable bicycling culture, and crime were the factors most consistently related to participants perceiving an objectively assessed high bikeable environment as low bikeable.

Table 9 Binary logistic model for respondents living in high bikeable environments but perceiving them as low bikeable

	Coef.		Odds ratio
Social demographics			
Male without children	ref.		
Female Without Children	-0.677	**	0.508
Male with Children	-1.615	***	0.199
Female with children	0.852	***	2.344
Age: 18-34	ref.		
Age:35-54	-0.644	***	0.525
Age: 55 or older	1.303	***	3.680
Education: college degree or above	ref.		
Education: below college degree	0.521	***	1.683
Income: $50,000 or higher	ref.		
Income: less than $50,000	1.357	***	3.883
Self-reported health condition (1-5)	-0.217	**	0.805
Years lived in current neighborhood	-0.049	***	0.952
# vehicles in the home	0.474	***	1.606
Attitudes			
Pro-bike	-0.102		0.903
Pro-transit	0.071		1.074
Pro-car	-0.045		0.956
Pro-walk	-0.075	***	0.928
Travel is negative	0.115	***	1.122
Social environment			
Supporting social environment for bicycling	-0.107	*	0.899
Perceived crime rate in the neighborhood	0.765	***	2.148
Behavior			
I never ride a bike	ref.		
I ride a bike occasionally	-1.069	***	0.343
I ride a bike regularly	-1.490	**	0.225
constant	-0.973		0.378
Model Statistics			
Number of observations	101		
Log-likelihood at 0	-65.173		
Log-likelihood at convergence	-47.682		
Pseudo R2	0.268		

Note: * p<.1, ** p<.05, *** p<.01

CONCLUSIONS AND POLICY IMPLICATIONS

This study aimed to explore the environment-behavior mechanism by investigating the mismatch between the objective and perceived environment, and factors contributing to this mismatch. The mismatch between perceptions and the actual environment might be one of the reasons resulting in the lower rates of active travel behavior among the residents living in objectively-defined walkable and bikeable neighborhoods. Exploring the mismatch problem, therefore, could be important for identifying potential interventions for promoting active travel behavior. Even though several recent studies have examined the mismatch problem under the context of walking behavior, there is little such research on bicycling. Relying on the data from a random phone survey of adults in the Portland, Oregon region, this study empirically tested the potential relationships between objective and perceived built-environment, and bicycling behavior, and factors that may intervene in these relationships.

Results of this study indicate that there was some agreement between perceptions and the objectively measured bicycling environment, but that inconsistencies exist. Several methodological challenges can explain the mismatches. First, it is difficult to objectively define and measure bikeability. A good bicycling environment may mean different environmental attributes for different people for different bicycling purposes. For example, a bicycle commuter may prefer an environment featuring with dedicated bicycle infrastructure, while another bicyclist riding for daily errands may like an accessible environment. A better understanding of the built environment is needed for different types of bicyclists and for different bicycling purpose is necessary. Second, measurement error in GIS measures may also contribute to the weak associations. Major measurement error in GIS-based measures can be introduced by incomplete records of the built environmental data, lack of information on the quality and size of the infrastructure and business establishments, and different buffer size used for defining the neighborhood. Third, perception-based measures may also be subject to measurement error. All the perception measures are derived from survey in this study, however, the survey instruments may not exactly captured the perceptions of the environment, and individuals may not correctly interpret the survey questions.

In addition, perceptions of the environment reflect an individual's interaction with the environment, involving an awareness and perception of the outside world through our primary receptive senses such as sight, smell, hearing, taste and touch, and all these sensory inputs are then integrated to form our cognitive representation of the environment [36]. A mix of individual and societal factors, such as gender, social class, personal values, place attachment, local culture, social norms, past experiences, physical capacity, and individual personal characteristics may influence the understanding of these cognitive representation, and perceptions of environment therefore may not correspond to objective reality. Therefore, different people might form different mental maps of the same built environment and consequently behave differently [37]. Further, studies have found that there are significant discrepancies between researcher and resident-defined neighborhood boundaries [38, 39]. Further, individuals who live in close proximity can differ markedly from one another in how they define the spatial dimension of their neighborhoods [38]. In this study, we used a fixed buffer size (one mile) as objective neighborhood boundary for all the residents. This brings another challenge to compare the objective and perceived neighborhood environment. Finally, the objective and perceived measures do not match up perfectly in this study. For example, we could not include a specific objective measure to correspond to the perceived measure on overall satisfaction with neighborhood design in terms of bike safety.

Even if these methodological challenges are solved, people's perceptions and objective measures are unlikely to always match. Further analysis on the factors contributing the mismatches we found identify that certain demographic, attitudinal, social, and behavioral factors are associated with a mismatch as we measured it. This indicated that interventions aimed at changing perceptions that are tailored to the people with the following characteristics may be most effective: lower socioeconomic status, women having children in the household, older adults, those having bad health condition, new movers into the neighborhood, and owning several cars. This strategy can be particularly effective and efficient when perception interventions aim to those who already lived in bike-friendly neighborhoods. This study also found social environment can play a role in the relationship between objective and perceived environment. For example, receiving less support for bicycling from family and friends and a

perception of high crime in the neighborhood prevent residents living in high bikeable neighborhoods to have positive perceptions of the environment. This implies that strategies aiming to encourage a supportive culture for bicycling and reduce neighborhood crime (and perceptions of crime) are necessary for promoting bicycling. This is consistent with other bicycling studies that find social culture is important in encouraging bicycling [40, 41].

Results of this study also indicate that actual and perceived built-environment both are associated with the bicycling behavior, particularly for utilitarian bicycling. For recreational bicycling, the objective environment attributes measured in this study are not significant factors, while the perceptions do matter. It is possible that people drive to places far from their home to bike for recreation, and therefore their neighborhood environment may not be relevant for their recreational bicycling. It is also possible that the bicycling environment measured in this study is not well applicable for recreational bicycling. Further, the relative effects of objective and perceived environment on bicycling behavior vary among different bicycling purpose.

For utilitarian bicycling, the objective environment is more important than the perceived environment. This is evidenced by the fact that the respondents who live in low objective bikeability environments have consistently low levels of utilitarian bicycling no matter they hold high or low perceptions. The perceptions only matters for utilitarian bicycling in high or moderate bicycling environment. By contrast, the perceptions may play stronger effect on recreational bicycling than the objective environment. Even though the differences are not statistically significant, the labeled moderate bicycling environment, featured with many bicycle lanes and off-street bicycle paths/trails, seems more supportive for recreational bicycling than the labeled high bicycling environment with more bicycling destinations and low traffic streets. Moreover, persons with more positive perceptions of the environment generally bicycled more than those with low perceptions no matter what actual environment they lived. This is true for both utilitarian and recreational bicycling. This finding indicates that perceptions are as important as the built environment in promoting bicycling behavior.

Many of our findings indicate that intervention programs to improve people's perceptions of the environment will further help to reap the full potential of planning and design policies, especially targeting the population group with low perceptions but living in an objectively high bikeable environment. Possible interventions to change perceptions include neighborhood-based marketing materials that include information on the location of safe bicycle routes, bicycle safety facts and tips, and locations of bicycle-accessible businesses and destinations. Public bicycling events, such "ciclovias" and the city of Portland's Sunday Parkways, that close streets to cars for several hours can also familiarize residents with the bicycle-friendly designs in their neighborhood. Wayfinding signage that includes bicycling distances and travel times to key destinations may also change perceptions. More "hands on" programs involving matching experienced and new bicyclists may also help change perceptions.

The findings of this study also help to explain the mixed findings from recent work on walking behavior and/or physical activity. Several recent studies found that perceptions may play a much larger role than the objective environment [6, 13, 42]. However, other studies found that objective environment had stronger associations with walking and/or physical activity than perceptions [4, 43]. Based on the findings of this study, one of the reasons contributing to the inconsistent findings is that previous studies did not differ the behavior based on purpose. Results of this study indicate that the relative effects of objective and perceived environment on behavior may vary depending on the purpose of the travel.

This study also confirms the finding from a recent study [5] that found the relative effects of perceptions on travel mode choice depend on residential neighborhood type. In particular, they found the travel mode choice is more determined by urban characteristics and not by personal perceptions in urban settings, but perceptions do become more important in the suburban and rural areas. In our study, however, we found that perceptions of the environment only matters for utilitarian bicycling in high and/or moderate level of objective bikeability environment, while for recreational bicycling, perceptions do become more important in low bikeability environment.

The present work begings to investigate the relationship between mismatch of objective and perceived built environment and bicycling behavior. Future research can improve this study by including

more precise and matched measures of objective and perceived environment. Exploring the variations of the mismatch among different socio-demographic groups and at different context (e.g. urban vs. suburban/rural) would also be enlightening.

ACKNOWLEDGMENTS

This research was funded by the Oregon Transportation Research and Education Consortium (OTREC), a national university transportation center funded by the US Department of Transportation, and the City of Portland. The analysis and interpretation and any errors are solely those of the authors.

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