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Do people's perceptions of neighborhood bikeability match "reality"?

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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 being a low-bikeable environment. In addition to the socio-demographics, this study also found that the social environment can play a role in the relationship between the objective and perceived environment. Finally, results of this study indicated that both the actual and perceived built environment are associated with bicycling behavior, particularly for utilitarian bicycling. For recreational bicycling, the objective environment attributes measured in this study are not significant factors, while perceptions do matter.

Keywords: bicycling, built environment, perceived measure, objective measure

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1 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 (Brownson et al. 2009; Sallis 2009). Perceived measures are generally obtained from interviews or self-administered questionnaires; objective measures are typically derived from systematic observations, audits, or geographic information system (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 (Ball et al. 2008; Gebel, Bauman, and Owen 2009; Gebel et al. 2011; Handy, Cao, and Mokhtarian 2006; Kirtland et al. 2003; Lackey and Kaczynski 2009; Lin and

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Moudon 2010; Ma, Dill, and Mohr 2014; McCormack et al. 2007; McGinn et al. 2007; Prins et al. 2009; Van Acker, Derudder, and Witlox 2013).

The mismatch between the perceived and objective environment is one of the reasons leading to mixed findings from the travel behavior/built environment studies (Ma and Dill 2015; Van Acker, Derudder, and Witlox 2013; Van Acker, Van Wee, and Witlox 2010). This is also one of the reasons that not all people, even in "pedestrian-friendly" and "bike-friendly" environments, choose to walk and bicycle (Van Acker, Derudder, and Witlox 2013; Van Acker, Van Wee, and Witox 2010). Improved understanding of the relationships between the objective and perceived environment and travel behavior could be important for understanding the mechanism underlying the relationship between the built environment and behavior and for identifying potential interventions (Handy, Cao, and Mokhtarian 2006; McMillan 2005; Sallis et al. 2006). However, few empirical studies have explored the magnitude and effects of the mismatch between perceptions and objective measures, particularly on bicycling behavior. Further, there is little known about 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 and (2) investigate the characteristics of the people whose perceptions do not match the objectively measured environment. We are particularly interested in why people living in a presumably high-bikeable environment perceive it as a low-bikeable environment. We do so using survey data from a large random sample survey of adults in the Portland, Oregon, metropolitan area.

2 Previous research

Recent studies have examined the concordance between the perceived and objectively measured environment, comparing their different roles on physical activity. Most of these studies are published in health journals. Though the initial purpose of these studies is often to investigate the validity of survey instruments, 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 errors inherent in 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 (Gebel et al. 2011).

Most of these studies find that agreement or concordance between the objective and perceived (also referred to as "subjective") built environment is poor to moderate based on kappa statistics. Kirtland et al. (2003) conducted a telephone survey to investigate walking environments in Sumter County, South Carolina. Using kappa statistics, this study found a fair to low agreement between subjective and objective measures. McCormack et al. (2007) 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. (2007) used a telephone survey (n=1270) in Forsyth County, North Carolina, and Jackson, Mississippi, and also found a poor agreement between perceived and objective measures. Ball et al. (2008) investigated the concordance between self-reported and objective (i.e., audit) measures of physical activity facilities based on a self-report survey of 1540 women from 45 neighborhoods in Melbourne, Australia, and found relatively poor agreement. Lackey and Kaczynski (2009) examined how the individual, neighborhood, and park-related variables influenced the agreement between self-reported and objectively measured distance to parks, and also found that agreement was poor; however, agreement was higher in certain subgroups. Prins et al. (2009) explored the degree of agreement between objective and perceived availability of physical activity facilities in neighborhoods 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. (2003) found that those engaging in physical activity tended to have higher agreement than inactive individuals. McCormack et al. (2007) 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 compared to 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. (2008) 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 two years. Lackey and Kaczynski (2009) 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, Bauman, and Owen (2009) 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 a low-walkable neighborhood. McGinn et al. (2007) also investigated whether the agreement varied between active and inactive people but found no significant difference.

3 Methodology

The data were obtained through a random phone survey of adults in the Portland region. The sample included both landline and mobile phone numbers and was conducted from July 19 to 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 percent. Even with the large sample and use of mobile phones, the sample was not perfectly representative of the population. The respondents were more likely to be female (58 percent vs. 51 percent for the region) and older (average age of 51 years of age versus 46 for the region). More details about the survey are available in Dill and McNeil (2014).

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, Derudder, and Witlox (2013) 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 (Blashfield and Aldenderfer 1978).

Our measures of bikeability are based on the growing literature linking bicycle infrastructure, the built environment, and bicycling. A number of studies have found that striped bicycle lanes (Buehler and Pucher 2012; Dill and Carr 2003; Krizek and Johnson 2006); off-street bike paths (Akar, Fischer, and Namgung 2013; Dill and Voros 2007; Parkin, Wardman, and Page 2008); bicycle boulevards

(Broach, Dill, and Gliebe 2012); and low-traffic streets are associated with more bicycling (Emond, Tang, and Handy 2009; Winters et al. 2010). 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 recreational purposes (Beenackers et al. 2012; Cervero et al. 2009). Also, accessibility to destinations is consistently found to be associated with both bicycling propensity and bicycling frequency (Emond and Handy 2012; Handy and Xing, 2011; Parkin, Wardman, and Page 2008; Xing, Handy, and Mokhtarian, 2010).

For perceptions of bikeability, we used the following indicators: (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," and (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 0.125-mile, 0.25-mile, 0.5-mile, and 1-mile circular and network buffers and distance to the nearest off-street bike path were created to match with the perceptions of off-street paths. After a series of comparisons of different sets of variables, we decided to use the following objective indicators to measure bikeability because they have stronger associations with the perception measures: miles of off-street bike paths within a 1-mile network buffer; miles of bike lanes within a 1-mile network buffer; miles of minor streets within a 1-mile network buffer; number of common destinations (e.g., convenience stores, grocery stores, restaurants and bars, beauty salons, postal service, etc.) within a 1-mile network buffer; street connectivity (defined as number of street intersections with three or more valences divided by total number of intersections) within a 1-mile network buffer; and hilliness (defined as the ratio of area with a slope equal or higher than 25 percent) within a 1-mile network buffer. These objective measures have been proven 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 attempted to match the perceived and objective measures, they do not 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 used 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.

Initially, the factor analysis was conducted based on the six indicators of perceived bikeability. The item "Many of the places I need to get to regularly are within biking distance of my home" was eliminated because it failed to meet a minimum criterion of having a primary factor loading of 0.4 and above. The factor analysis using the remaining five items was examined. The initial eigenvalues showed that the first factor explained 51 percent of the variance, the next four factors had eigenvalues of less than one, with each explaining 8-15 percent of the variance. We decided to use the one factor with an eigenvalue of 1.0 or higher. The factor-loading matrix is provided in Table 1. This factor represents an overall positive perception of the bicycling environment. It has positive loadings on perceptions of the presence of bike lanes, bike paths and quiet streets, and bike safety, and it has negative loadings on the perception of traffic that makes it difficult or unpleasant to bicycle. The same method was used for a factor analysis based on the seven indicators of objective bikeability. The initial eigenvalues showed that the first factor explained 45 percent of the variance, and the second factor explained 20 percent of the variance, with values greater than one. The third, fourth, fifth, sixth, and seventh factors had eigenvalues of less than one, explaining 12 percent, 11 percent, 5 percent, 4 percent, and 3 percent of the variance, respectively. Different factor solutions were examined using varimax rotations of the factor-loading matrix, which did not improve the results. We chose the original two-factor solution, which explained 65 percent of the variance, because of the leveling off of eigenvalues on the scree plot after two factors, the insufficient number of primary loadings, and the difficulty of interpreting the third and subsequent factors. The factor-loading matrix of this two-factor solution is presented in Table 2. Two items loaded in the same direction and with similar magnitudes (over 0.4 or under -0.4) for each factor, but were retained: slope (hilliness) and the number of destinations nearby. Hilliness is an important factor in bicycling and would rarely be considered a positive attribute. Similarly, trip length is a major constraint for bicycling; not having destinations nearby would be a limitation for most adults. Looking at the remaining five variables, the two extracted factors represent two different dimensions of bicycling environment: (1) street network, which consists of street connectivity, quiet streets, and bike boulevards; and (2) separated bicycle infrastructure, which consists of bicycle lanes and paths.

Table 1: Factor analysis for perceived bikeability

	Perception of bicycling environment
There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to.	.756
There are bike lanes that are easy to get to.	.777
There are quiet streets, without bike lanes, that are easy to get to on a bike.	.692
There is so much traffic along nearby streets that it would make it difficult or unpleasant to bike.	-.612
How satisfied are you with your neighborhood design in terms of bike safety?	.715

Table 2: Factor analysis for objective bikeability

	Factor 1: Street network	Factor 2: Separated bicycle infrastructure
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

Following the strategy used by Van Acker, Derudder, and Witlox (2013), two cluster analyses were conducted based on the extracted factors using the hierarchical cluster with Wald's method. This procedure aims to assign participants who shared similar characteristics in perceptions or who lived in similar bicycling environments to a cluster. The cluster analysis based on the perception factor led to the identification of two groups with a clear contrast in perceptions of the bicycling environment (see Figure 1). Perception Cluster 1 has significantly higher perceptions of the bicycling environment than Perception Cluster 2. We, therefore, named Perception Cluster 1 as high perception and Perception Cluster 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 (see Figure 1). Examining the descriptive statistics for each cluster, as well as the factors, we developed the following labels and descriptions of the three:

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

Even though Objective Cluster 1 was labeled more bikeable than Objective Cluster 2, the two groups may represent two different types of a "good" environment for bicycling. The environment of Objective Cluster 1 is better in terms of destination accessibility and street connectivity and does not rely on separated bike infrastructure. Instead, cyclists can use well-connected low-traffic residential streets and bike boulevards. Objective Cluster 2's environment has more dedicated bicycle infrastructure (on-street lanes and separate paths), but often without the connected network of low-traffic streets. It is possible that some bicyclists prefer the environment of Objective Cluster 2 than that of Objective Cluster 1 or that preferences vary depending on the bicycle trip purpose. Based on these data, we cannot identify a group that combines the merits of Objective Cluster 1 and Objective Cluster 2—flat areas with destinations nearby, connected low-traffic streets, bike boulevards, bike lanes, and separate paths. It seems there is a difference between the underlying street environment and separated bicycle infrastructure. We chose to label Objective Cluster 1 as "high" in this analysis because our previous work with a different dataset found that the physical characteristics found in Objective Cluster 1 had stronger associations with neighborhood bicycling than did the presence of striped bike lanes (Dill, Mohr, and Ma 2014). That study also found that it is useful to look at bicycle infrastructure separately from other built-environment characteristics.

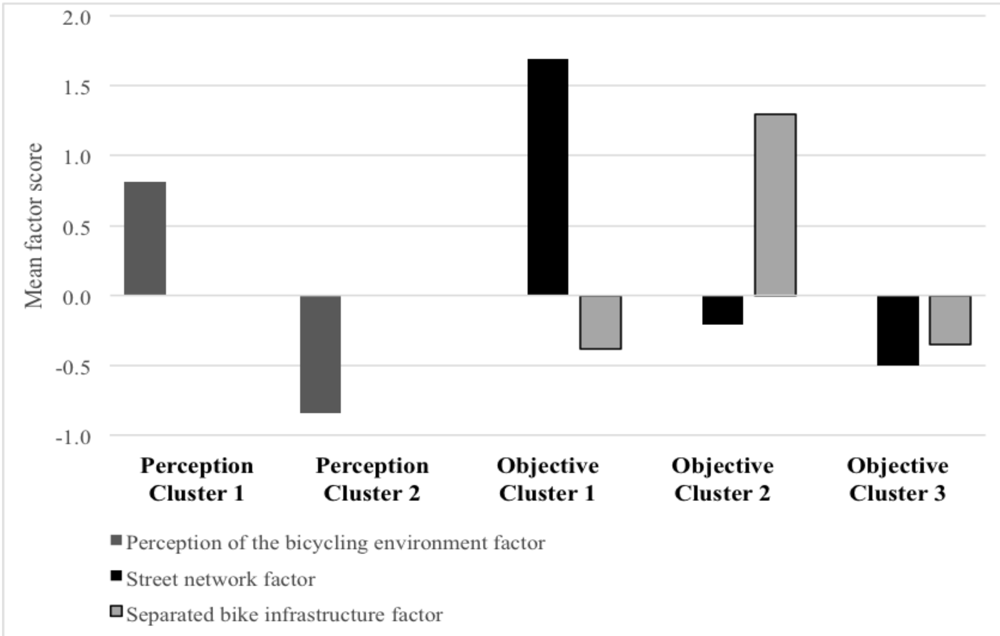


Figure 1: Cluster analysis on perceived and objective bicycling environment

4 Results

A disaggregate exploration of different groups of participants reveals that not all residents who live in a high-bikeable neighborhood perceive it as high, and not all residents living in a low-bikeable neighborhood perceive it as low (see Table 3). About 44 percent of the participants perceived their environment at the same level as the objective measure of the bikeable environment, while about 7 percent perceived their relatively good cycling environment as poor, and about 28 percent perceived their poor cycling environment as good. In addition, about 11 percent perceived the moderate-bikeability environment as high, while about 10 percent 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.

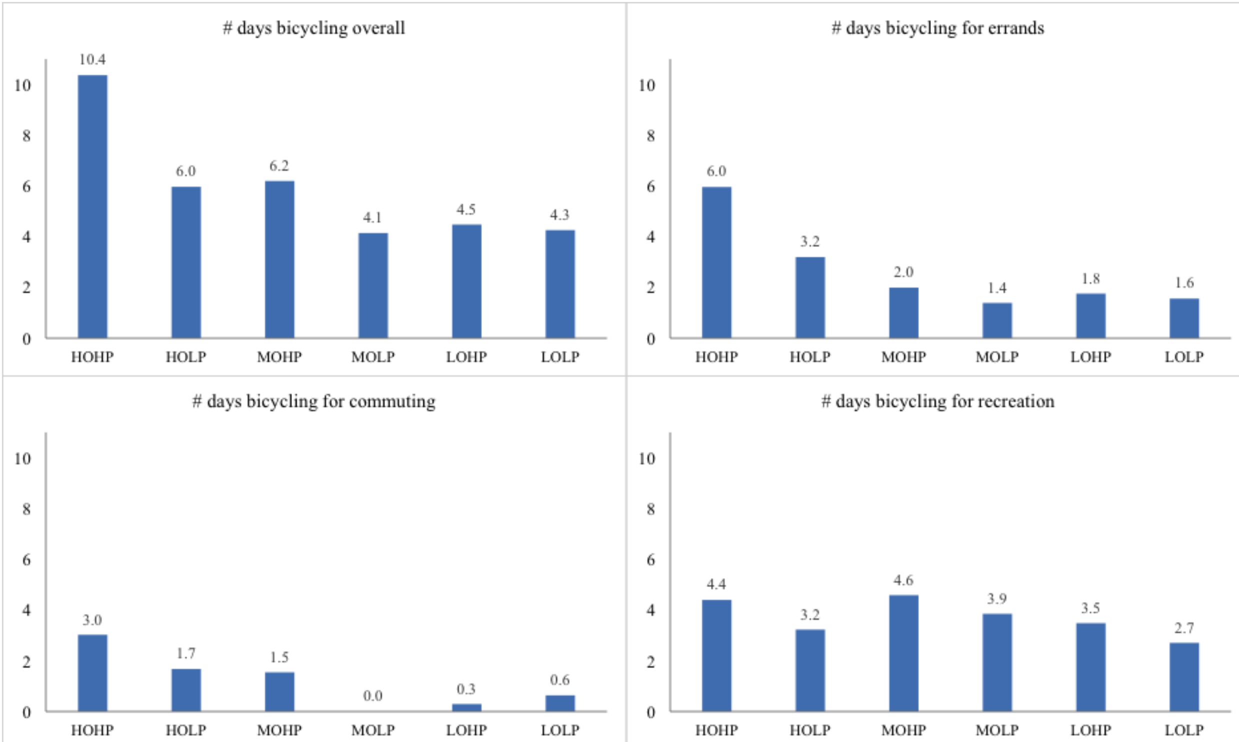
Table 3: Match and mismatch between perceived and objective bikeability

			Perception of Bike Environment		
			High Perception	Low Perception	Total
Objectively Measured Bikeable Environment	High bikeability	Count	83	46	129
		% within high bikeability	64%	36%	100%
		% of total	12%	7%	19%
	Moderate bikeability	Count	77	66	143
		% within moderate bikeability	54%	46%	100%
		% of Total	11%	10%	21%
	Low bikeability	Count	187	219	406
		% within low bikeability	46%	54%	100%
			28%	32%	60%
Total		Count	347	331	678
		% of total	51%	49%	100%

4.1 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 matched and mismatched groups (Figure 2). It is evident that for both overall and utilitarian bicycling frequency goes down as the objective bicycling environment worsens. Bicycling frequency for recreational purposes does not vary significantly among different levels of the objective environment. 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. It is also possible that the bicycling environment measured in this study is not very applicable to recreational bicycling. Persons with more positive perceptions of the environment often bicycled more than those with low perceptions, no matter what actual environment existed where they lived. Overall, the highest rates of bicycling were among people who lived in high-objective environments that perceived the environment as bikeable.

The relationships between the objective and perceived environment and bicycling behavior vary among the different trip purposes (Figure 2 and Table 4). For bicycling for daily errands, there is a difference in the high-objective environment between people with low vs. high perceptions (HOHP vs. HOLP), but not in the moderate- or low-objective environments. In contrast, for commuting, there is a difference between people with low and high perceptions only in the moderate-objective environment (MOHP vs. MOLP). This implies that a mismatch in high-objective environments may not matter for commuting but could influence bicycling for errands. For both errands and commuting, bicycling is low in both low-objective groups, and a mismatch (high perceptions) cannot overcome the poor-objective environment. This indicates that a mismatch of perceptions in environments objectively suitable for bicycling (either our high or moderate measures) may lead to reduced levels of bicycling for transportation. Therefore, understanding those mismatches may help in increasing rates of bicycling.



Note: HO=High-Objective Environment; MO=Moderate-Objective Environment; LO=Low-Objective Environment; HP=High Perceptions; LP=Low Perceptions.

Figure 2: Comparisons of bicycling frequency among different groups

Table 4: ANOVA test of the difference in group mean

	Overall bicycling	Bicycling for Errands	Bicycling for Commuting	Bicycling for Recreation
HO vs. MO vs. LO	0.00	0.00	0.00	0.10
HP vs. LP	0.00	0.01	0.06	0.04
HOHP vs. HOLP	0.02	0.05	0.24	0.29
MOHP vs. MOLP	0.14	0.43	0.03	0.56
LOHP vs. LOLP	0.41	0.70	0.20	0.13

Note: The cells are the p-values derived from ANOVA tests.

4.2 Mismatch and socio-demographics, attitudes, social environment, and neighborhood safety

A mix of individual and societal factors likely contributes to the mismatch between the objective and perceived environment. The socio-demographic attributes of participants, their attitudes, and the social environment within each match and mismatch category 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 (Table 5). 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 (Ball et al. 2008;

Gebel, Bauman, and Owen 2009), this study did not find significant differences in respondents' health conditions and years lived in their current neighborhoods between matched and mismatched groups.

People living in high-bikeable environments generally have more positive attitudes toward biking, transit, and walking and more negative attitudes toward cars; such differences are not as pronounced in the other environments. People with low perceptions of the environment had lower levels of social support, at least in the high- and low-objective environments. Finally, those who perceive their environment as less bikeable also thought crime rates were high in their neighborhood in the high- and moderate-objective neighborhoods.

Table 5: 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%	51%	68%**	58%	58%
Age	47.4	53.0**	50.9	51.1	50.1	54.9***
Children in household	46%	28%*	36%	33%	39%	29%**
Education [1]	6.2	5.8	5.4	5.1	5.8	5.9
Income [2]	4.5	2.8***	3.8	3.5	4.5	4.6
Self-reported health condition [3]	3.7	3.5	3.5	3.4	3.7	3.8
Years living in current home	13.6	13.2	14.4	14.9	14.8	14.5
Travel attitudes [4]						
Pro-bike	0.77	0.22***	0.20	-0.10*	0.35	-0.05***
Pro-transit	0.20	0.03	-0.06	0.12	0.03	-0.11
Pro-walk	0.33	0.36	0.10	0.00	-0.02	0.01
Pro-car	-0.3	-0.32	-0.03	-0.13	0.07	0.25**
Negative travel	-0.21	-0.04	0.06	0.02	-0.06	0.12*
Social environment						
Social norms [5]	3.40	2.95**	2.68	2.43	2.72	2.36***
Neighborhood safety						
There is a high crime rate in my neighborhood [6]	1.59	1.87*	1.76	2.23**	1.39	1.35

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

[1] 1= Less than 8 years; 2= Some high school (9-12 years), without a diploma; 3= High school Diploma or GED; 4= Associate Degree or technical or vocational school; 5= Some college, but no degree; 6= Bachelor's degree; 7= Some graduate study, but no degree; 8= Graduate or professional degree

[2] 0=Less than $15,000; 1= $15,000 to less than $25,000; 2= $25,000 to less than $35,000; 3= $35,000 to less than $50,000; 4= $50,000 to less than $75,000; 5= $75,000 to less than $100,000; 6= $100,000 to less than $150,000; 7= $150,000 or more

[3] 1=Poor; 2=Fair; 3=Good; 4=Very Good; 5=Excellent

[4] Five attitudinal variables were derived from a factor analysis based on 26 survey questions (available upon request)

[5] Social norms are the means of three survey questions (available upon request)

[6] 1= Strongly disagree; 2= Somewhat disagree; 3= Somewhat agree; 4= Strongly agree

4.3 Regression analysis

The main objective of this analysis is to understand the factors that may contribute to a mismatch between people's perceptions and objective measures of the environment, at least as we have defined them. People who live in a high-bikeable neighborhood but who perceive it as low bikeable (HOLP) 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, attitudes toward transportation, social environment, and bicycling behavior. Similarly, binary logistic models were estimated comparing MOLP to MOHP and LOHP to LOLP (Table 6). In all cases, odds ratios greater than one indicate that the variable may contribute to a person being in the mismatch group (HOLP, MOLP, or LOHP).

The model comparing HOLP to HOHP explains about 25 percent of the variation of the dependent variable. It suggests that women with children are more likely to perceive their high-bikeable neighborhoods as low bikeable, compared with men without children. Compared with people aged 18-34, 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 environments as low. Those without a college degree are 68 percent 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 environments as low than those with a relatively high income (equal to or above $50,000 per year). Those who reported good health and have lived in their neighborhood for a longer time are less likely to perceive high-bikeable environments as low. Having more motor vehicles at home contributed to greater mismatch.

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. It is surprising to note that the attitude toward bicycling was not significant. This is probably due to the significant associations between the socio-demographic variables and bicycling attitude. The social environment does play a role in the relationship between the objective and perceived environment. A supportive social environment for bicycling helps to reduce the mismatch, while high crime rates in a 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.

The models examining mismatch in the moderate- and low-objective environments have lower explanatory power and fewer significant variables, indicating that these relationships are harder to explain. The only variable that was significant in all three models is the number of vehicles, although in the moderate- and low-objective environments having more vehicles contributes to less mismatch. Similar to the HOLP model, people with positive attitudes toward walking are less likely to be mismatched, while perceptions of crime contributes to greater mismatch. Females without children and males with children living in low-bikeable neighborhoods are more likely to perceive them as high-bikeable (LOHP) neighborhoods, compared to males without children. Age, education, and income did not predict mismatches in the moderate- and low-bikeable neighborhoods. In the low-bikeable areas, better health was associated with perceiving the area as low bikeable, as was holding negative attitudes toward travel. Also in the low-bikeable environment, having more social support for bicycling was associated with perceiving the environment as bikeable, a mismatch. Those who bicycle regularly were also more likely to perceive their low-objective environment as bikeable. It is also interesting to note that a pro-bike attitude was not significant in either of the three models. This is partially because of the correlations between the pro-bike attitude and the variables interacting with gender and children.

Table 6: Binary logistic models for HOLP, MOLP, and LOHP

	HOLP (vs. HOHP)			MOLP (vs. MOHP)			LOHP(vs. LOLP)		
	Odds ratio	95% Conf. Interval		Odds ratio	95% Conf. Interval		Odds ratio	95% Conf. Interval	
Social demographics									
Male without children	ref.			ref.			ref.		
Female without children	0.51	(0.28-0.91)	**	1.09	(0.26-4.51)		2.00	(1.18-3.41)	**
Male with children	0.20	(0.14-0.28)	***	0.95	(0.24-3.74)		2.85	(1.70-4.78)	***
Female with children	2.34	(2.11-2.60)	***	1.79	(0.27-12.07)		1.51	(0.73-3.14)	
Age: 18-34	ref.			ref.			ref.		
Age: 35-54	0.53	(0.42-0.66)	***	1.54	(0.14-16.91)		1.28	(0.61-2.70)	
Age: 55 or older	3.68	(2.48-5.46)	***	1.09	(0.25-4.65)		0.88	(0.38-2.03)	
Education: college degree or above	ref.			ref.			ref.		
Education: below college degree	1.68	(1.43-1.98)	***	0.61	(0.13-2.93)		1.07	(0.67-1.71)	
Income: $50,000 or higher	ref.			ref.			ref.		
Income: less than $50,000	3.88	(2.29-6.58)	***	0.79	(0.24-2.64)		0.82	(0.43-1.56)	
Self-reported health condition (1-5)	0.80	(0.66-0.99)	**	0.87	(0.69-1.11)		0.75	(0.62-0.92)	***
Years lived in current neighborhood	0.95	(0.93-0.98)	***	1.01	(0.95-1.08)		1.02	(0.99-1.05)	
# vehicles in the home	1.61	(1.60-1.62)	***	0.66	(0.42-1.04)	*	0.73	(0.59-0.91)	***
Attitudes									
Pro-bike	0.90	(0.78-1.04)		1.00	(0.71-1.40)		1.11	(0.74-1.68)	
Pro-transit	1.07	(0.87-1.33)		1.34	(1.00-1.80)	*	1.12	(0.93-1.35)	
Pro-car	0.96	(0.72-1.27)		1.06	(0.70-1.62)		1.24	(0.80-1.92)	
Pro-walk	0.93	(0.90-0.96)	***	0.72	(0.52-0.99)	**	1.14	(0.84-1.53)	
Travel is negative	1.12	(1.12-1.13)	***	1.01	(0.67-1.52)		0.75	(0.60-0.93)	***
Social environment									
Supporting social environment for bicycling	0.90	(0.79-1.02)	*	0.75	(0.49-1.16)		1.42	(1.08-1.86)	**
Perceived crime rate in the neighborhood	2.15	(2.00-2.30)	***	1.96	(1.40-2.75)	***	0.99	(0.73-1.35)	
Behavior									
I never ride a bike	ref.			ref.			ref.		
I ride a bike occasionally	0.34	(0.29-0.40)	***	1.37	(0.56-3.33)		1.80	(0.86-3.77)	
I ride a bike regularly	0.23	(0.07-0.71)	**	0.34	(0.06-1.80)		2.53	(0.99-6.45)	*
constant	0.38	(0.07-1.94)		1.56	(0.07-33.39)		0.58	(0.12-2.76)	
Model Statistics									
Number of observations	101			109			311		
Log-likelihood at 0	-65.173			-75.328			-215.374		
Log-likelihood at convergence	-47.682			-62.447			-191.214		
Pseudo R2	0.268			0.171			0.112		

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

5 Conclusions and policy implications

This study aimed to explore 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 for 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, either by changing perceptions or the environment. 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 the objective and perceived built environment and the factors that may contribute to these relationships.

Results of this study indicate that there was some agreement between perceptions and the objectively measured bicycling environment, but 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 and/or for different bicycling purposes. For example, a bicycle commuter may prefer an environment featuring dedicated bicycle infrastructure, while another bicyclist riding for daily errands may like an accessible environment. Women and men may view the same environment differently based on their tolerance for risk. A better understanding of the built environment is needed for different types of bicyclists and for different bicycling purposes. 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-environment data, lack of information on the quality and size of the infrastructure and business establishments, and different buffer sizes used for defining the neighborhood. Third, perception-based measures may also be subject to measurement error. All of the perception measures in this study are derived from a survey. However, the survey instrument may not have 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 primary receptive senses such as sight, smell, hearing, taste, and touch. All of these sensory inputs are then integrated to form our cognitive representation of the environment (Sherrington 1961). 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 representations, and perceptions of the environment may not correspond to objective reality. Therefore, different people might form different mental maps of the same built environment and consequently behave differently (Ewing and Handy 2009). Studies have found that there are significant discrepancies between researcher- and resident-defined neighborhood boundaries (Coulton et al. 2013; Coulton et al. 2001). Further, individuals who live in close proximity can differ markedly from one another in how they define the spatial dimension of their neighborhoods (Coulton et al. 2001). In this study, we used a fixed buffer size (1 mile) as an objective neighborhood boundary for all 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 of overall satisfaction with neighborhood design in terms of bike safety.

Despite the challenge in measuring and matching the objective and perceived measures, we included most of the key indicators that are commonly used in the literature for defining an objective or perceived bicycling environment. Also, the composite measures based on factor analysis help to reduce the measurement and mismatching errors from individual variables. Therefore, to a large extent, the mismatch groups we defined likely reveal the real mismatches between the objective environment and subjective perceptions.

We were best able to predict the factors contributing to a mismatch in the high-objective environments, as we measured them. Those factors included certain demographics, attitudes, measures of the social environment, and bicycling behavior. There are two possible policy implications of these findings. On the one hand, interventions aimed at changing perceptions may be most effective if tailored to people with the following characteristics: lower socioeconomic status, women with children in the household, older adults, and people in poorer health. Possible interventions 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 as "ciclovias" and the city of Portland's Sunday Parkways, which close streets to cars for several hours, can also familiarize residents with the bicycle-friendly designs in their neighborhood. Way-finding 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 fact that we found that people who lived in high-objective environments who biked more also had high perceptions of the environment may indicate that bicycling more in a neighborhood may influence perceptions positively.

On the other hand, the mismatch among certain demographic groups may reveal that our objective definition of a high-bikeable environment may not meet the needs of these groups. New types of bike infrastructure or other amenities may be needed to encourage these groups of people to bicycle. Moreover, people who have low perceptions of bikeability, even if they live in objectively defined high-bikeable neighborhoods, are underrepresented in many bike advocacy efforts and local transportation decisions (Aimen and Morris 2012). Meanwhile, it is worth noting that only a small share of the population lived in high-bikeable areas (Table 3), and perceptions did not have significant effects on bicycling in low-bikeable environments (Table 4). This implies that, for bicycling behavior, simply having a positive perception of the environment may not be enough to overcome the barriers of the physical environment. Therefore, changing perceptions of people in low-bikeable areas will have a limited overall effect. Changing the objective environment across neighborhoods is still very important.

This study also found that the social environment can play a role in the relationship between the objective and perceived environment. For example, receiving less support for bicycling from family and friends and a perception of high crime in the neighborhood may prevent residents living in high-bikeable neighborhoods to perceive them as bikeable. 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 (Handy, Xing, and Buehler 2010; Pucher and Buehler 2012).

Moreover, it may be a combination of perceptions and objective measures in different contexts that matters. Our findings are consistent with the result from a recent study (Van Acker, Derudder, and Witlox 2013) that found the relative effects of perceptions on travel-mode choice depend on residential neighborhood type. In particular, the study found that travel-mode choice is determined more 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 analysis, we found that perceptions of the environment made a difference in frequency of bicycling for errands in high-objective bikeable environments and for commuting in moderate-objective environments. In other words, perceptions may have different effects in different contexts.

The present work begins to investigate the relationship between the mismatch of the objective and perceived built environment for bicycling. Future research can improve this study by including more precise and matched measures of the objective and perceived environment. In particular, we recommend exploring how definitions of bikeability vary among demographic groups and how to incorporate that into research and practice. Exploring the variations of the mismatch among different socio-demographic groups and at different contexts (e.g., urban vs. suburban/rural) would also be enlightening.

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