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Bicycle boulevards and changes in physical activity and active transportation: Findings from a natural experiment

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ABSTRACT

Objective. This study evaluates changes in physical activity and active transportation associated with installation of new bicycle boulevards.

Methods. This natural experiment study uses data from a longitudinal panel of adults with children ($n = 353$) in Portland, OR. Activity and active transportation outcomes were measured with GPS and accelerometers worn for up to 5 days in 2010–11 and 2012–13. The effect of the treatment was estimated using difference in differences estimation and multivariate regression models.

Results. In five of the seven models, the interaction term was not significant, indicating that after controlling for the main effects of time and exposure separately, there was no correlation between being in a treatment area and minutes of moderate and vigorous physical activity (MVPA) per day, bicycling >10 min, walking >20 min, minutes of walking (if >20), or making a bike trip. Significant covariates included rain, being female, living closer to downtown, and attitudes towards bicycling, walking, and car safety.

Conclusion. This study could not confirm an increase in physical activity or active transportation among adults with children living near newly installed bicycle boulevards. Additional pre/post studies are encouraged, as well as research on the length of time after installation that behavior change is likely to occur.

Introduction

Having safe places to bicycle is important in achieving higher levels of cycling among both adults (Handy and Xing, 2011; Heinen et al., 2010; Sallis et al., 2013) and children (Stewart, 2011). Most research has focused on two types of infrastructure, on-street bicycle lanes and separated paths, which are the most common in North America (Pucher et al., 2010). Both striped bike lanes and separated paths have been correlated with bicycle commuting (Buehler and Pucher, 2012). Few observational studies have examined a third type of bicycle infrastructure: bicycle boulevards. Bicycle boulevards are low-volume streets, often residential, that use traffic calming, diversion, signage, and intersection treatments to reduce the speed and volume of motor vehicles and create a better environment for people on bicycles (National Association of City Transportation Officials, 2014; Walker et al., 2009). A study using GPS found that regular bicyclists went out of their way to use bicycle boulevards, more so than for striped bike lanes (Broach et al., 2012). A stated preference survey found that both current and potential cyclists had stronger preferences for residential streets with traffic calming than for major city streets with striped bike lanes (Winters and Teschke, 2010). In addition to infrastructure, several studies have found that attitudes can play a significant role in predicting whether and how much people bicycle (or bicycle and walk) (Cao et al., 2009; Handy and Xing, 2011; Heesch et al., 2012; Miller and Handy, 2012; Titze et al., 2007, 2008; Vernez-Moudon et al., 2005).

Several reviews of research assessing the effects of new infrastructure on bicycling and walking activity have noted the lack of prospective or longitudinal research designs, particularly with control groups (Krizek et al., 2009; Ogilvie et al., 2007; Pucher et al., 2010; Yang et al., 2010). A review of 52 studies of trails published between 1980 and 2008 only found one that included pre/post data with a comparison group (Starnes et al., 2011). That study (Brownson et al., 2004) examined the promotion of trails, not new trail construction, and did not find a significant change in overall walking activity. Similarly, two other longitudinal studies without controls did not find a change in walking activity associated with trail promotion (Merom et al., 2003) or trail construction (Evenson et al., 2005). All three of these studies used surveys and self-reported measures of activity. The studies of trail promotion (Brownson et al., 2004; Merom et al., 2003) conducted surveys immediately following the intervention, while Evenson et al. (2005) collected data two months following trail construction. A review of 25 studies of bicycle interventions identified three that included changes in bicycle infrastructure, all at a community- or city-scale, and all found significant increases in bicycling (Yang et al., 2010).

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The lack of longitudinal studies of infrastructure changes with adequate controls likely reflects the difficulties in conducting such research. In their review, Yang et al. (2010) noted the challenge of identifying appropriate controls and lack of agreement on how to measure bicycling behavior. Only two of the six studies of interventions that focused on bicycling had comparable outcome measures, limiting findings regarding effect sizes. Construction delay has been noted as a limitation in two "natural experiment" studies (Evenson et al., 2005; Ogilvie et al., 2010). The reliance on self-reported data noted by Yang et al. (2010) reflects the costs and respondent burden associated with more objective measures.

The aim of this study is to evaluate changes in physical activity and active transportation associated with installation of new bicycle boulevards using a longitudinal, panel design with a control group. Based upon existing cross-sectional research, we hypothesized that levels of active transportation would increase in the neighborhoods with the bicycle boulevard treatment, while controlling for socio-demographics and attitudes.

Methods

Recruitment and data collection

This analysis uses data from the Family Activity Study (FAS), a longitudinal panel study in Portland, Oregon, designed as a natural experiment. The study areas include 8 street segments scheduled by the city for bicycle boulevard installation (0.9 to 4.2 miles long) and 11 control street segments (1.0 to 5.7 miles long). The control streets were selected to be similar in urban form and demographic characteristics, particularly with respect to access to bicycle infrastructure, and were often parallel streets several blocks away. Households within 1000 ft of the selected streets were recruited to participate through a flyer left at the front door of every accessible housing unit and mailed invitations for inaccessible units ($n = 54{,}381$). Potential participants were screened for eligibility. At least one child aged 5 to 17 and one adult parent or guardian had to agree to participate for the length of the study; both had to be physically able to ride a bicycle, have access to a working bicycle, and not be intending to move in the near future. Participants were not told that the study was related to installation of bicycle boulevards or any other infrastructure. A total of 335 families participated in the pre-data collection phase, representing 3.1% of the estimated eligible population (American Community Survey 2007–2011 5-year estimates, households with children aged 6–17).

For data collection purposes, the sample consisted of two groups based upon the anticipated date of boulevard installation. Data collection dates and weather information for each group appear in Table 1. Both groups include both treatment and control households, and the groups are combined in the data analysis. Data collection methods at both points in time included surveys, accelerometers (Actigraph GT3X), and person-based GPS (GlobalSat DG-100, 4-second intervals). Survey instruments and data collection protocols were approved by the Human Subjects Research Review Committee at Portland State University. Participants were asked to wear the GPS and accelerometer units for five consecutive days. Deployments were scheduled to include at least one weekend day, and post deployments were usually scheduled to start within one week (two years later) of the pre deployment. GPS and accelerometer data were processed by the research team and GeoStats (now Westat) to match the GPS and accelerometer data streams (fifteen-second epochs) based on date/time stamps.

This analysis presents data from the adults in the study. The number of adult study participants with valid data in each phase is shown in Table 2. Retention in the study was higher among the treatment group. This may reflect one limitation of a natural experiment. The city may have chosen to install bicycle boulevards in locations where residents were supportive of new bicycle infrastructure. This could correlate with stronger interest in the study, though study participants were not told that the study purpose was to evaluate the effect of the new facilities.

Table 2
Number of participants with valid data, by phase and group.

	Group	Pre[a]	Pre & post[b]	Retention
3 or more 10 + hour days of activity data	All	429	293	68%
	Treatment	215	154	72%
	Control	214	139	65%
3 or more days of GPS data	All	471	341	72%
	Treatment	231	177	77%
	Control	240	164	68%
Survey completed	All	490	353	72%
	Treatment	237	183	77%
	Control	253	170	67%

Location: Portland, Oregon, USA.
[a] 2010-11.
[b] 2012-13.

Measures and sample characteristics

Demographics. Demographics were collected by survey and are shown in Table 3. Comparing the demographics of the participants with only pre data to those with both pre and post data, there were no differences with respect to gender or employment status. Retention was higher among adults who were in excellent health (self-reported), had lower BMI (based upon self-reported data), were married, and were college graduates. For participants with both pre and post data, the adults in the treatment group were slightly more likely to be employed full-time, be married, and have a four-year college degree.

Objective environment. Data from the Regional Land Information System (RLIS) maintained by the Portland regional planning agency (Metro) and the City of Portland Bureau of Transportation was used to develop objective measures of the environment. The treatment and control households are in predominantly single-family neighborhoods with equal access to bike lanes (Table 4). The treatment households have better access to sidewalks and are somewhat closer to downtown.

Data from the NOAA Global Historical Climatology Network was used for the number of days of rain during the GPS data collection days. Data are from the Portland International Airport station, which is within 2–9 miles of each of the study areas.

Attitudes. Attitudes towards bicycling, walking, and driving were measured using a series of questions developed by Mokhtarian and Handy (Cao et al., 2006) and a 5-point scale (1 = strongly disagree to 5 = strongly agree). A variable measuring attitudes toward bicycling is the average response to the following statements: I like riding a bike, biking can sometimes be easier for me than driving, and I prefer to bike rather than drive whenever possible (Cronbach's alpha = 0.840). Similarly, the walking attitudes variable is the average response to the following statements: I like walking, walking can sometimes be easier for me than driving, and I prefer to walk rather than drive whenever possible (Cronbach's alpha = 0.658). Attitudes towards the relative safety of a car was measured by the following statements: traveling by car is safer

Table 1
Data collection timeframe.

	Group 1	Group 2
Pre-installation	$n = 307$ adults July 17, 2010 to November 8, 2010 High temperature (F): 51–98, avg. = 72 Low temperature (F): 38–63, avg. = 53	$n = 183$ adults April 27, 2011 to September 4, 2011 High temperature (F): 52–96, avg. = 72 Low temperature (F): 38–66, avg. = 53
Post-installation	$n = 240$ adults August 1, 2012 – November 4, 2012 High temperature range (F): 52–102, avg. = 75 Low temperature range (F): 40–65, avg. = 53	$n = 123$ adults April 27, 2013 – August 6, 2013 High temperature range (F): 50–97, avg. = 76 Low temperature range (F): 40–66, avg. = 54

Table 3
Participant demographic characteristics.

	Group	Pre[a]		Pre & Post[b]	
		% or mean	*n* (in group)	% or mean	*n* (in group)
% female	Treatment	61%	236	63%	182
	Control	64%	250	67%	168
Excellent or Very Good health	Treatment	65%	235	67%	181
	Control	60%	250	65%	168
Employed full-time	Treatment	56%	235	54%	181
	Control	48%	250	49%	168
Married	Treatment	60%	234	64%	180
	Control	56%	248	58%	167
4-year college degree	Treatment	63%	236	66%	182
	Control	55%	249	61%	168
Mean age (at start of study)	Treatment	43.1	233	43.3	180
	Control	40.8	247	41.0	166
Age 35–44 years (at start of study)	Treatment	53%	233	53%	180
	Control	49%	247	51%	166
BMI	Treatment	25.4	234	25.2	182
	Control	26.1	244	25.5	166

Location: Portland, Oregon, USA.
[a] 2010-11.
[b] 2012-13.

overall than riding a bicycle; traveling by car is safer overall than taking transit; and traveling by car is safer overall than walking (Cronbach's alpha = 0.750).

Participants in the treatment areas had slightly more positive attitudes towards bicycling (treatment = 3.84, control = 3.65, $p = 0.07$) and walking (treatment = 4.03, control = 3.89, $p = 0.09$). Conversely, participants in the control areas had stronger agreement with the statements about car safety (control = 2.75, treatment = 2.53, $p = 0.01$).

Physical activity and active transportation. Minutes of moderate and vigorous physical activity (MVPA) was calculated for days with at least 10 h of wear time using NHANES cut-points for each minute of activity. Participants did not complete diaries identifying their mode of travel. Therefore, travel by active transportation modes (walking and bicycling) was imputed using both the GPS and accelerometer data in a multinomial logit model. The model successfully predicted 95% of walk trips and 79% of bicycle trips based upon a follow-up survey from a sample of participants (Broach et al., 2014). Resulting outcome measures include whether the participant made a bicycle or walking trip (yes/no), the number of bicycle and walking trips, whether the participant bicycled more than 10 min or walked more than 20 min, and the number of minutes walking or bicycling (Table 5).

Data analysis. To assess the effect of the bicycle boulevard treatment, we used difference in difference estimation with binomial logit regression, negative binomial regression, or linear regression, depending upon the form and distribution of the dependent variable. The difference in difference method is often used to analyze pre/post data with treatment and control groups (Angrist and Pischke, 2009) and has been used to examine the effects of a public bicycle share program (Fuller et al., 2013). Generally, the models compare the difference in outcomes for the treatment and control groups in the pre and post periods by using an interaction term (treatment × period). All models were limited to participants with at least three valid days of activity data and complete surveys in both the pre and post phases. We tested several demographic, geographic, and attitudinal covariates; those included in the models were significant in at least one of the models.

Active transportation engagement and frequency were modelled separately. The first model estimated whether the participant engaged in the activity at all (made a bike trip) or above a certain threshold (10 min of bicycling, 20 min of walking). The second model estimated the number of trips or minutes only for those participants that engaged in the activity. This approach was taken for two reasons. First, for bicycling in particular, a large share of participants did not engage in the activity. In the pre phase, 40% of participants who also collected post data bicycled 0 min and another 19% only bicycled 1–10 min over the five days. Estimating a logistic regression model for the activity engagement (yes/no) separately from frequency of engagement (for those engaging) is one method to appropriately model skewed data with many zeroes (Fletcher et al., 2005). Walking behavior was not quite as skewed, though 19% walked only 20 min or less over the five days. Second, the factors influencing the decision to engage in an activity at all may differ from decisions regarding the frequency of doing that activity. This has been shown with respect to owning a bicycle and riding frequency (Sallis et al., 2013).

Table 4
Objective environment measures of participating households.

	Treatment (mean)	Control (mean)	*p*
Land area single-family residential (%)[a]	83%	82%	0.49
Distance to downtown (network, miles)	5.0	5.6	0.00
Bike lanes (miles)[a]	0.13	0.14	0.68
Crosswalks (number)[a]	4.51	3.92	0.28
Streets with sidewalk (%)[a]	90%	69%	0.00
Streets with slope 4% or greater (%)[a]	3.4%	4.6%	0.33
n[b]	125	121	

[a]Calculated using a 1/4 mile network buffer.
[b]Includes households with at least one adult with Pre and Post data.
Portland, Oregon, USA, 2010.

Results

The estimated model coefficients appear in Table 6. In five of the seven models, the interaction term (treatment × post phase) was not significant ($p > 0.10$), indicating that after controlling for the main effects of time and exposure to the treatment separately, there was no correlation between being in a treatment area after bicycle boulevard installation and minutes of MVPA per day, bicycling more than 10 min, walking more than 20 min, minutes of walking (if >20), or making a bike trip. The interaction term was negatively correlated with minutes of bicycling (if >10, $p = 0.00$) and the number of bike trips (if >0, $p = 0.06$).

Several of the covariates were significant. Rain was negatively correlated with whether participants biked more than 10 min, made a bike trip, and minutes of walking. Living closer to downtown was associated with higher levels of MVPA and greater engagement in bicycling (>10 min, made a bike trip) and walking (>20 min). Women engaged in fewer MVPA and minutes of bicycling, but were more likely to walk more than 20 min. Attitudes towards bicycling and walking were generally positively correlated with engaging in those activities, while participants who feel that cars are safer than other modes were less likely to bicycle.

Table 5
Outcome Measures by Treatment and Control Groups, by Phase.

	Treatment		Control	
	Pre	Post	Pre	Post
Minutes MVPA per day mean (std. dev.)	39.5 (21.9) $n = 139$	35.6 (19.0) $n = 139$	35.4 (20.8) $n = 121$	34.8 (19.4) $n = 121$
Difference: Post - Pre Minutes MVPA per day mean (std. dev.)	−3.83 (17.7) $n = 139$		−0.59 (19.5) $n = 139$	
Biked >10 min	43.9% $n = 139$	45.3% $n = 139$	39.7% $n = 121$	31.4% $n = 121$
Minutes biked (if > 10) mean (std. dev.)	103.9 (73.0) $n = 61$	65.9 (74.7) $n = 63$	76.8 (69.4) $n = 48$	72.7 (55.3) $n = 38$
Difference: Post - Pre Minutes biked mean (std. dev.)	−48.7 (98.1) $n = 61$		−34.1 (64.2) $n = 48$	
Walked >20	83.5% $n = 139$	75.6% $n = 139$	79.3% $n = 121$	74.4% $n = 121$
Minutes walked (if >20) mean (std. dev.)	107.2 (79.1) $n = 116$	89.4 (66.8) $n = 105$	92.0 (86.9) $n = 96$	75.4 (66.5) $n = 90$
Difference: Post - Pre Minutes walked mean (std. dev.)	−29.0 (87.2) $n = 116$		−24.2 (71.89) $n = 96$	
Made a bike trip	61.1% $n = 139$	58.2% $n = 139$	55.4% $n = 121$	52.9% $n = 121$
Number of bike trips (if >0)mean (std. dev.)	5.6 (4.9) $n = 85$	4.4 (4.2) $n = 81$	4.3 (3.8) $n = 67$	3.5 (3.3) $n = 64$
Difference: Post - Pre Number of bike trips mean (std. dev.)	−2.4 (4.9) $n = 85$		−1.4 (3.9) $n = 67$	

Location: Portland, Oregon, USA. Pre-phase: 2010–11. Post-phase: 2012–13.

Discussion

The models could not confirm the hypothesis that bicycle boulevards will increase active transportation and physical activity. In fact, for two of the outcome measures (bicycling minutes and trips) there was a negative correlation. The model results are consistent with several other studies that find that attitudes are very influential in predicting bicycling behavior (Handy et al., 2006; Heinen et al., 2013; Miller and Handy, 2012; Titze et al., 2007) and that women are less likely to bicycle for transportation (Garrard et al., 2008; Heesch et al., 2012).

The reason for the findings with respect to the bicycle boulevard installation is unclear, though there are several possibilities. First, post data collection may have occurred too soon. Behavior change may not occur in a quick timeframe, particularly a change from no bicycling to bicycling (engagement) and as a result of an infrastructure change that may not appear as a major change for some residents. Installation of the boulevards often took more than a year, with speed humps and pavement markings going in early and crossing improvements taking longer to install. The amount of time between installation and post data collection varied between two and twelve months. Moreover, some elements of two of the nine projects were not completed within the study timeframe. Other longitudinal studies of changes to bicycle infrastructure had follow-up periods of up to three years (Yang et al., 2010).

Second, changes in behavior at the individual level between the two time periods vary greatly for both the treatment and control groups (Table 5), making expected changes due to the treatment difficult to detect. This variation may reflect the nature of this type of activity, as well

Table 6
Difference in Differences models of physical activity and active transportation.

	B (p-value)						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	MVPA per day	Biked >10 min	Minutes biked (if > 10)	Walked >20	Minutes walked (if >20)	Made a bike trip	Number of bike trips (if >0)
Phase: Post (pre is ref)	**0.066 (0.00)**	−0.217 (0.52)	**0.513 (0.01)**	−0.206 (0.54)	−0.088 (0.45)	0.006 (0.98)	0.306 (0.06)
Treatment (control is ref)	2.054 (0.41)	−0.600 (0.39)	**0.323 (0.05)**	0.299 (0.69)	0.035 (0.75)	0.020 (0.97)	0.184 (0.21)
Post x Treatment	−3.44 (0.33)	0.201 (0.655)	**−1.09 (0.00)**	−0.162 (0.73)	−0.096 (0.54)	−0.158 (0.69)	−0.395 (0.06)
# rain days	−0.50 (0.31)	**−0.311 (0.00)**	−0.044 (0.23)	−0.032 (0.618)	−0.037 (0.09)	**−0.171 (0.00)**	−0.017 (0.58)
Distance to downtown	**−1.19 (0.05)**	−0.142 (0.06)	0.002 (0.96)	**−0.217 (0.01)**	0.002 (0.95)	**−0.177 (0.01)**	0.021 (0.594)
Female	**−4.46 (0.02)**	**−0.475 (0.04)**	**−0.311 (0.01)**	**0.616 (0.01)**	0.084 (0.30)	**−0.580 (0.01)**	−0.080 (0.45)
Bike attitudes	1.34 (0.23)	**1.472 (0.00)**	**0.455 (0.00)**	not included	not included	**0.668 (0.00)**	**0.538 (0.00)**
Walk attitudes	**3.07 (0.02)**	not included	not included	**1.016 (0.00)**	**0.242 (0.00)**	not included	not included
Car safety attitudes	not included	**−0.292 (0.05)**	−0.141 (0.09)	0.120 (0.42)	−0.030 (0.58)	−0.050 (0.70)	**−0.178 (0.02)**
Model form	Linear	Binary logit	Negative binomial, with number of valid days as offset variable	Binary logit	Negative binomial, with number of valid activity days as offset variable	Binary logit	Negative binomial, with number of days with GPS data as offset variable
n (number of individuals, each with pre- and post-phase data)	255	255	101	255	195	255	145

Location: Portland, Oregon, USA. Pre-phase: 2010–11. Post-phase: 2012–13.
Significant coefficients ($p < =0.05$) in boldface.

as unknown changes in the physical or social environment, perhaps specific to certain study areas. Similar variation appears in short-term count data available; data from the city of Portland for 10 locations along seven of the boulevards from 2011 and 2013 show that the number of bicycles went up at six locations and down at four, with an average un-weighted change of +22%. Other studies have found relatively small changes in behavior from larger-scale infrastructure interventions, such as an increase in bicycle trips per person of 0.06 per day (Yang et al., 2010). Detecting small effects in outcome measures with large variation is difficult. Third (and related), the design of each bicycle boulevard treatment differed, particularly regarding crossing treatments. Some projects included more substantial investments, such as a pocket park, flashing beacons, curb extensions, and extensive landscaping. Others consisted primarily of more subtle changes, including speed humps, sharrow markings, changed stop signs, and signage.

Fourth, the negative correlation with bicycling minutes could reflect the benefit of the boulevards in providing a more direct preferred route and making crossing busy streets more timely with the provision of signs, signals, and other devices. However, this explanation does not apply to the negative correlation with the number of bicycle trips. Fifth, the significant correlations with bicycling frequency, but not engagement, may indicate that bicycling frequency is more variable over time and influenced by other factors not included in this analysis. Finally, the effect of the new facility on travel would be highly dependent upon where participants are traveling to from home. If, for example, a household is located near one end of the boulevard and most of their travel is in the other direction, the effect could be non-existent.

The main strengths of this study include the use of a panel design and control group, which allows for greater causal inference. Limitations stem from the nature of a natural experiment, where there is no control over the timing and design of the treatment. In this study, installation of the bicycle boulevards was delayed significantly, limiting the time between installation completion and post data collection. Because the projects varied in design depending upon pre conditions, all treatment participants were not exposed to exactly the same type of treatment. Other limitations relate to the longitudinal design. Retention rates did vary, with higher retention in the treatment areas and among participants with lower BMI and better self-reported health status. The relatively small sample size limited the analyses that could be conducted, such as controlling for unique effects of each corridor. The study also only included adults with children, whose behavior likely differs from other adults and may be more difficult to change. The data collection methods (GPS and accelerometers) may change behavior, particularly during the pre-installation phase when the novelty of the devices and study is fresh; since our treatment participants had slightly more positive attitudes towards active transportation, this bias could result in differences between the treatment and control. Finally, travel modes (bicycling and walking) were imputed using a regression model, which introduces error.

Conclusions

This study did not show an increase in physical activity or active transportation associated with installation of bicycle boulevards among adults with children. Other cross-sectional (Broach et al., 2012) and stated preference (Dill and McNeil, 2013; Winters and Teschke, 2010) studies have indicated a preference for these types of facilities. Therefore, additional pre/post studies are encouraged. Additional research is also necessary on the length of time after installation that behavior change is likely to occur and the appropriate study design. Combining panel data with observations and/or intercept methods may be more robust. Analyzing route choice behavior may also reveal the effects of the facilities (Broach et al., 2012).

Conflict of interest statement

The authors do not have conflicts of interest to declare.

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