TO BIKE OR NOT TO BIKE: SEASONAL FACTORS FOR BICYCLE COMMUTING

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ABSTRACT

The objective of this research was to assess the impact of weather on commuting to work by bicycle among a panel of working adults in northern communities. Our participants commuted at least two miles each way and bike commuted more than twice annually. Transportation mode was recorded for four seven-day periods in 2009-2010 (each period in one of four seasons. Mode, personal characteristics, and commute length were linked to location- and time-specific weather conditions, and daylight hours on commuting days. Analyses focused on the effects of season, weather and other factors to develop binary models for commuting by bicycle. The likelihood of bike commuting increased 3% with every 1ºF increase in morning temperature and decreased by 5% with a 1mph increase in wind speed. Likelihood of biking to work was more than double on days with no morning precipitation. There was no discernible effect of hours of daylight, although study participants cited this as a barrier in the baseline survey. Distance to work negatively affected bike commuting likelihood and men were nearly twice as likely as women to bike commute on a given day. Separate models for men and women, suggested that men and women respond similarly to adverse weather conditions, although some effects were difficult to identify among women due to a smaller sample size. An appreciable portion of participants biked to work throughout the year in a variety of weather conditions suggesting that a northern climate may not necessarily preclude year-round bike commuting. Multi-modal commuting was prevalent among our sample: on 20% of the days participants reported biking to work, they reported getting home via another mode. Helping cyclists learn to deal safely with cold and dark conditions and facilitation of multi-modal bicycle commuting may promote wider use of bicycle commuting and serve to extend the northern bicycle commute season.

INTRODUCTION

Northern and rural communities are particularly challenging environments in which to provide transportation options that ensure people have year-round access to work, services, and social activities as well as active, healthy travel options. Concerns about health, environment, energy consumption, and transportation costs have increased interest in use of non-motorized transport, such as bicycling and walking, for utilitarian purposes (American Public Health Association, 2009; Dora and Phillips, 2000). Although current levels of bicycle use as a share of travel modes are low in the U.S., they are much higher in countries with similar levels of development and weather conditions, including winter climates (Pucher and Dijkstra, 2003). Greater attention to built environment factors that facilitate biking and walking may increase the use of these travel modes, at least for relatively short trips (Pucher, et al., 2010). Non-design factors such as the natural environment, community culture, and personal characteristics are also likely to be important in understanding decisions to use bicycles for routine travel purposes. In this study, we focus on measuring the seasonal variation in bicycle commute travel in smaller northern communities and associated causes of this variation to inform development of policies and programs that might promote year-round use or extend the bicycle commuting season for existing bicycle commuters.

LITERATURE REVIEW

Increases in use of bicycling and walking are among the alternatives available for reducing reliance on automobile travel, at least for shorter trip lengths in more urban areas. The advantages of a shift in trip shares to non-motorized transportation include health and social, as well as economic and environmental benefits. Factors hypothesized to influence utilization of cycling and walking for utilitarian transportation purposes have included a wide range of possibilities including trip and personal characteristics, land-use patterns, population density, community design, and infrastructure facilitating non-motorized transport.

The impact of seasonal differences, including ambient temperature, type and amount of precipitation, and hours of daylight, has been included in some of these analyses, but has not received much attention as a focused research topic. These seasonally-related issues are a particular concern in northern regions of the United States, especially in the north central and north east regions, where all of these factors vary substantially across the annual seasonal cycle. Better information about the impact of these relatively predictable factors on decisions to utilize non-motorized transportation would contribute to improved ability to predict potential demand for infrastructure and accommodation to facilitate use of bicycling and walking as transportation alternatives. This summary focuses on issues specific to bicycling, but many of the same considerations may apply as well to choice of walking as a transportation mode.

A broad picture of the role of bicycle travel for utilitarian purposes is available from U.S. Census Bureau journey to work data. In the 2000 Census, 0.4% of respondents reported that their usual mode of transport to work was bicycle, in contrast to 87.9% who reported usually taking an automobile (Pucher and Buehler, 2006). The share in northern New England was somewhat lower: 0.3% for Vermont and 0.2% for New Hampshire and Maine (Pucher and Buehler, 2006). For the nation as a whole, the share of people biking to work has not increased since these data were first collected in 1980. Bicycle trips for all purposes were reported to have a higher share of 0.8% in the National Household Travel Survey (NHTS) of 2001. These shares stand in contrast to Canadian data showing a 1.2% bicycle share of work trips despite the disadvantages of a more northern latitude, and much higher rates in Europe (Pucher and Dijkstra, 2003).

Research focusing on understanding modal choice of cycling has utilized multiple data sources, including seasonal climate and weather data, to identify key factors. Cervero and Duncan (2003) analyzed individual daily activity responses from the 2000 Bay Area Travel Survey (BATS), limiting the trips included to shorter distances originating from residences. Trip records were combined with other data, measuring factors such as topography, daylight/darkness, precipitation, neighborhood security, population density, land use zoning, and urban design. The bicycle share of the trips <=5 miles sampled was 1.5%. The predictive model for bicycle choice included as significant factors trip distance, darkness, and gender, but not precipitation; among the built environment characteristics, urban design and land use diversity were positively associated with the decision to use a bicycle though not at conventional levels of statistical significance.

Pucher and Buehler (2006) used a research strategy that focused only on community-level variables to explore differences in the bicycling share of work trips between the U.S. and Canada. The bike share of work trips was regressed on multiple potential predictors for 59 States and Provinces in these two countries. Significant predictors included weather variables (precipitation and temperature) and policy variables (gasoline price and cycling fatality rate); median length of trip to work was marginally significant. A similar study focused only on U.S. Census Bureau data from standard metropolitan areas found that higher urban densities, more temperate climates, and high proportions of college students were associated with greater bicycle shares for nondiscretionary travel (Baltes, 1996). Other community-level analyses have focused on the role of cycling facilities, such as bike pathways in promoting bicycle commuting. Nelson and Allen (1997) used data from 18 U.S. cities to demonstrate a positive association between the bicycle share and pathways, using climatic factors as control variables, a result confirmed in a larger study by Dill and Carr (2003). These results indicate the importance of multiple factors in understanding bicycle mode choice, including trip and personal characteristics, the built environment, and seasonal and climatic factors.

Several studies of the effects of climate and seasonality on bicycle utilization reported from outside the U.S. provide a more detailed orientation to the issues. Bergstrom and Magnusson (2003) reported on surveys of employees at two large firms in Sweden where the overall bicycle share of trips was reported to be 11%. These surveys focused on estimating the potential for expanding the bicycle share of trips during winter. Distance traveled to work and season were both strong predictors of travel mode choice, with the impact of distance stronger in winter than in summer. All-season cyclists valued exercise, cost and the environment as highly important, while summer-only cyclists reported high importance of temperature, precipitation, and road conditions. Darkness, surprisingly, was not given much importance as a factor by any category of survey participant. Respondents reported potential increases in winter bicycle travel if road surface conditions were improved and snow clearing was the most important of the road conditions cited by respondents. This report suggests that in Sweden travel choices between auto and bicycle are influenced by weather and season factors, among others, and that some of these factors could be addressed by infrastructure development and maintenance policies.

A multi-method survey of cycling behavior under varying weather and seasonal conditions at three university campuses was reported from Australia by Nankervis (1999). This study included a linkage of counts of parked bicycles to weather conditions (temperature, wind speed, and precipitation), and surveys of students. Effects of seasonal climate on utilization of bicycles for travel to these campuses were observed, with a modest decline observed in winter months. Analyses of the impact of specific daily weather conditions on bicycle counts showed that all three weather elements were significant factors on utilization but with modest explanatory power (overall weather construct r=0.34) in this atypical population. Rain at the time of trip initiation appeared to be the single-most influential individual weather circumstance, based on findings across the data sets. These results demonstrated the feasibility of linking weather and season data to daily cycling behavior indicators, and suggest that weather and season had significant effects on travel mode decisions in this population.

A recent study utilized responses from about 60,000 individuals living in larger communities who participated in the 2003 Canadian Community Health Survey (Winters et al., 2007). Multilevel logistic regression analyses identified influential factors predicting the likelihood of utilitarian cycling among respondents from 53 communities. The proportion of respondents who reported cycling in each community ranged from 3.6% to 13.3%. Among the general (non-student) sample, gender, age, education, and income were significant predictors of cycling likelihood. Significant city-level climate variables included number of days/year with precipitation (odds ratio=0.84 95% CI=0.74-0.94) and number of days/year with freezing temperatures (odds ratio=0.91 95% CI=0.86-0.97).

This prior research indicates the general importance of seasonal and weather conditions on choice of bicycle travel mode, but there is a dearth of detailed information about the impact of specific factors (Heinen et al., 2010; Saneinejad, et al., 2010). Studies analyzing relationships between aggregate bicycle use data and community characteristics indicate that temperature and precipitation typically have significant effects, though of varying strength (Dill and Carr, 2003; Nelson and Allen, 1997; Parkin et al., 2008; Pucher and Buehler, 2006; Rose et al. 2010). Similar results are reported by studies focused on variations in bicycle traffic counts under varying weather conditions (Brandenburg et al., 2007; Buckley, 1982; Emmerson and Ryley, 1998; Nankervis, 1999; Niemeier, 1996).

In summary, several prior studies focused on individual bicycle use to better understand utilitarian travel mode choices. A limited number of these studies relate bicycle use to weather. Better information about factors influencing choices to use bicycles for utilitarian travel may contribute to improved policies and programs to support wider use of bicycling for everyday travel. The primary objective of this study was to describe the impact of specific weather conditions on daily use of bicycles for travel to work among a panel of working adults who commute by bicycle two or more miles each way.

DATA COLLECTION

This longitudinal study documented reports of whether commuter cyclists traveled to work by bicycle or another transportation mode on 28 pre-specified days over a 10 month period. The study was conducted in the northeastern state of Vermont, U.S.A. at approximately 44 degrees north latitude where annual weather conditions span a wide range. The sample goal was to obtain data for a diverse panel of at least 100 adult bicycle commuters. To meet these goals we set a target of 200 study participants and sub-targets of about one-third women, about one-half over age 40 years, and all-season bicycle commuters comprising no more than one-quarter. Other inclusion criteria were: age ≥18 years, regularly working outside of the home, commute to work distance of ≥2.0 miles; and bicycle commuting frequency of >2 annually. The one-way distance criterion was implemented to focus on those who were likely to use motorized transport as an alternative to bicycle commuting. Full-time students were excluded.

Descriptive data on potential participants were obtained from initial interviews and surveys. These were developed based on semi-structured individual exploratory interviews with five experienced bicycle commuters and four focus groups with male (n=12) and female (n=7) bicycle commuters followed by pilot tests of draft instruments. The baseline interview and survey provided data on personal characteristics and general bicycle use. Commuting logs were created on a survey website; uniquely-identified log forms were provided for each participant for each of their four assigned reporting periods. These forms collected data indicating whether each of these 28 days was a working day. If it was a working day, the mode of transportation to work, road conditions, and related information was collected.

Recruitment was conducted in five communities with relatively large worker populations: the Brattleboro, Burlington, Montpelier, St. Albans, and Rutland areas. The total population of the central communities plus their surrounding towns ranged from 44,513 to 156,545. Central communities generally are in valleys with surrounding towns in rolling hills. To reach a large audience of bicycle commuters, brief recruitment notices were sent to outdoor recreation groups, advocacy organizations, bicycle shops, selected workplaces, and similar groups for circulation to their email lists. Interested individuals were interviewed by telephone; if they met study criteria they were sent a baseline survey and were asked to circulate a recruitment notice to other potential participants.

Weather data specific to geographic location was linked to individual reports of commuting mode on these days. Weather data specific to geographic location, reporting day, and morning commuting hours were purchased from the Northeast Regional Climate Center. Most weather data were recorded at National Weather Service (NWS) first-order stations, typically located at regional airports. The five communities in which participants resided were served by four such stations. These sources provided data on average temperature and wind speed and total amount of precipitation during morning hours. Snow depth was reported by 18 NWS cooperating stations matched by postal code to participant residence locations. Location-specific hours of daylight were obtained from a standard source (www.usno.navy.mil/USNO).

Baseline interview and survey data were collected during May-July 2009. Participant commuting logs were completed during four seven-day periods spaced across seasonal changes in the months of September (mean temperature in Burlington, Vermont 62° F), January (18° F), April (43° F), and July (71° F). One-quarter of participants were randomly assigned to one week in each of these months to increase variability in weather conditions. Log data collection commenced in September 2009.

ANALYSIS

Daily log records for each participant were linked to baseline data by unique identifiers, and to weather and daylight data by location and date codes. The combined records were filtered to identify commuting days. The unit of analysis was person-day records for commuting days containing all indicated data. We used a generalized linear model to identify factors that influenced participants' decision to bike commute on each logged working day, while controlling for other factors that may influence these decisions. Our dependent variable was 'BIKED' (yes or no) with a binary distribution assigned to the model. To account for the correlation expected among observations collected from the same participant on multiple days, a repeated statement was included in the model.

From our models, we report parameter estimates and odds ratios for each factor. In addition to a model of all study participants, we also ran separate models for men and women. Because sample size was smaller for these models, especially for women, we create a new categorical variable, 'SEASON' to increase model power by reducing the number of model parameters. 'SEASON' is a class variable with four levels: summer, fall, winter, and spring. Models including 'SEASON' do not include the variables temperature, daylight, or snow depth since these factors should already be captured to some extent. We compared model fit within genders using QIC (quasi likelihood under the independent model criterion), a measure of quasi likelihood similar to an AIC value but more appropriate when using generalized linear model with a repeated component (Pan 2001). Like an AIC value, the number of model parameters is accounted in calculating the QIC, and a smaller value implies improved model fit. In contrast to an R-squared value, QIC values do not provide meaningful comparisons across models. For ease of interpretation and comparison, for the gender-specific models we report only the odds ratios.

Of the 210 individuals who responded to recruitment activities, 185 met the study criteria and completed baseline assessments. Attributes of these cyclists and their commute are tabulated in Tables 1 and 2. The planned balance of gender, age and residential location was achieved. Note that self-reported seasonal biking in Table 1 is not necessarily commuting. Participants were somewhat more likely to be ≥40 years of age than younger, with similar age distributions for men and women (Table 1). Nearly all (93%) had a four-year college degree, a higher proportion than the general Vermont adult population (33%). Nearly all (90%) reported excellent or very good health, also higher than Vermont adults in general (61%).

Table 1. Characteristics of survey respondents (n=185)

	%
Gender	
Male	62.6
Female	37.4
Age	
40 or under	41.1
40+	58.9
Urban/rural resident	
Urban	25
Rural	75
Do you bike in the……	
Summer	95.7
Fall	84.1
Winter	36.8
Spring	95.7
Education	
< 2 yr. degree	3.7
2 yr. degree	3.1
4 yr. degree	41.1
> 4 yr. degree	52.2
Health	
Excellent	47.2
Very good	42.9
Good	8.6
Fair or Poor	2.0
Distance to work	
2-5 miles	44.2
6-10 miles	31.4
> 10 miles	24.4

Table 2 illustrates a good range of route type and workplace amenities among the survey respondents. Work place amenities included facilities for personal clean-up, bicycle storage, and storage of work and bicycling clothing. In aggregate, the 170 participants reported on commuting modes for 120 unique calendar days during the four commuting log months. At least one of the participant reported biking to work on 103 of these 120 days. The total number of daily reports was 2,643 person-days of which 2,528 were days requiring a trip to work. Participants reported biking for at least some portion of their trip to work on 1,060 (41.9%) of these logged commuting days. Note at the bottom of Table 2, that for the largest number of surveys days participants drove alone to work. The limited walking is attributed to the requirement that participants live 2 miles from work. Nearly a fifth of days on which respondents reported biking to work were multi-modal (232 out of 1,060), that is, respondents used an additional mode of transport to either get to work or return home.

Table 2. Characteristics of respondent commute to work

Route Characteristics (mean ±SD)	
% commercial land use	42.5±31.0
% residential land use	39.4 ± 24.7
% rural land use	40.2 ± 27.8
Rating of workplace amenities for cycling (0-10, 10 high)	
0-3	5.0 %
4-6	28.6 %
7-10	66.5 %
Mode to and from work on designated survey days (person-days)	
Bicycle	828 (32.7%)
Solo car	1,080 (42.7%)
Ride share	151(6.0%)
Bus	18 (<1%)
Walk	19 (<1%)
Other	41 (1.6%)
Multi-model without bicycle portion	159 (6.3%)
Multi-modal with bicycle portion	232(9.2%)

The reasons for not commuting by bicycles are tabulated in Table 3. Although the reasons are diverse, weather comprises an appreciable portion of the record. Note that light conditions at both the start and end of the day were a factor. Schedule was cited second most often. There were no notable differences among men and women for reasons for not bike commuting (not presented).

Table 3. Respondent reported reasons for not bike commuting on a given survey day

Reason	**Frequency cited (person-days)**	**% commuting days not biked for this reason***
Too cold	418	16.5%
Schedule didn't allow	417	16.5%
Got dark too early	294	11.6%
Roads were too snowy or snow was forecast	290	11.5%
Roads were wet or rain was forecast	172	6.8%
Roads were icy	160	6.3%
Got light too late	159	6.3%
Had to transport a passenger	121	4.8%
Had to transport something that couldn't be carried on a bicycle	117	4.6%
Didn't have the energy	73	2.9%
Had to dress more formally then usual	24	0.9%
Too hot	19	0.8%
Could not wash up after commute	18	0.7%
Other (e.g., needed a car for work or errands during the day, lack of bike lanes on that day's route, bike not in working order)	430	17.0%

*Percents do not sum to 100 because respondents could cite more than one reason for not biking on a given day.

The variables included in the modeling effort are listed in Table 4, and include a variety of weather, demographics, and geographic factors. The percent of non-single occupancy vehicle (non-SOV) trips was included as a factor to determine whether those people more likely commute to work by bicycle were more likely in general to commute by alternative means. This variable was calculated based on reported mode of transport for each day of the study period. In general variables not statistically significant at the 0.05 level were excluded from the models. Tables 5 and 6 summarize weather information obtained from independent NWS sources for the days logged by participants. These data again illustrate robust variation in the dataset.

Table 4. Model variables.

Weather
Temperature (ºF)
Precipitation (inches)
Wind speed (mph)
Snow depth (inches)
Total daily hours of sunlight (hours)
SEASON (winter, spring, summer, or fall)
Demographic & Cyclist-specific
Gender
Age (years)
Rating of workplace cycling amenities (0-10 scale, 10 high)
% non-SOV commute trips
Geographic
Distance to work (miles)
% commute through commercial district
% commute through residential district
% commute through rural district

Table 5. Weather and daylight characteristics for days logged by participants.

	Range	Mean	Median
Temperature (°F)	-3.2 - 79.2	45.3	45.4
Wind (mph)	0.0 - 20.0	5.1	4.0
Precipitation (inches)	0.0 - 0.4	< 0.1	0.0
Snow depth (inches)	0.0 - 23.0	2.6	0.0
Daylight (hours)	9.0 - 15.4	12.4	12.7

Table 6. Study period weather characteristics (unit is person-days).

Person-days Biked		Precipitation		Snow on the ground		Season			
Yes	No	Yes	No	Yes	No	Winter	Spring	Summer	Fall
1,060	1,468	356	2,172	605	1,923	663	618	858	389

RESULTS

Our models of all study participants (both men and women) indicated that temperature, precipitation, wind speed, and gender were all highly significant factors affecting an individual's likelihood of bicycle commuting on a given day (Table 7). The likelihood of biking to work increased by 1% with every 3ºF increase in temperature, while likelihood decreased by 5% with every 1mph increase in wind speed. The absence of precipitation between 5:00 and 9:00 AM more than doubled the likelihood of biking. Men were nearly twice as likely to bike commute than women and above the age of 40, likelihood of biking increased by 2% with each additional year. Other than distance to work, the other route characteristics included in the model were not significant factors (% commercial district, % residential, and % rural), nor were the rating of workplace amenities or the % of non-SOV commute trips.

Table 7. Model parameter estimates and odds ratios for likelihood of bicycle commuting, all participants

Effect	Parameter Estimate	S.E.	Z	p	Odds Ratio Point Estimate	95% Confidence Interval	
Temperature (°F)	0.03	0.01	5.31	<0.001	1.03	1.02	1.04
Wind speed (mph)	-0.06	0.1	-3.85	<0.001	0.95	0.92	0.97
Precipitation (no vs. yes)	0.65	0.14	4.29	<0.001	2.65	1.42	2.57
Snow (inches)	-0.10	0.04	-2.55	0.01	0.90	0.84	0.98
Daylight (hours)	-0.001	0.001	-0.57	ns	1.00	0.99	1.00
Distance (miles)	-0.80	0.02	-4.17	<0.001	0.92	0.89	0.96
Age (years)	0.02	0.01	2.62	0.01	1.02	1.01	1.04
Gender (men vs. women)	0.98	0.21	4.51	<0.001	1.91	1.78	3.99

There was some overlap in the gender-specific model results. Temperature and wind speed remained significant effects of a similar magnitude. For women however, some variables significant in the general model were either marginally significant or not significant, due perhaps to a smaller sample size. For instance, distance to work had a slightly smaller effect (odds ratio = 0.95 among women vs. 0.92 in the general model), and was significant at an alpha level of 0.10. Snow depth and precipitation were not significant in the women's model. In contrast, the results for the male-specific model were on the whole consistent with those of the general model. Age, distance to work, and precipitation, among others, remained significant factors. The significance of snow depth declined slightly to p= 0.053.

According the model QIC values, for women, the more complete model with all factors performed better than the model containing the 'SEASON' variable. However, the effect of precipitation was more pronounced in the aggregated model than in the complete model. (p= 0.06 vs. p=0.17). For men, however, the QIC value was lower in the aggregated model including 'SEASON', indicating improved model fit. Overall, for men, results of the model including 'SEASON' were similar to those of the model for all respondents: respondent age, wind speed, and distance to work all remained significant factors (Tables 7,8). 'SEASON' was highly influential, with men 11 times more likely to bike in the summer than winter or fall and women 25 times more likely. Variability around this odds ratio was also considerably higher for women. Wind speed, precipitation, and distance to work were marginally significant for women in this model. Age was not a significant factor for women in the model using SEASON.

Table 8. Odds ratios for likelihood of men and women bicycle commuting

	Women				Men			
Effect	Odds Ratio Point Estimate	95% Confidence Interval		p	Odds Ratio Point Estimate	95% Confidence Interval		p
Temperature (°F)	1.04	1.02	1.06	0.003	1.03	1.01	1.04	<0.001
Wind speed (mph)	0.95	0.90	0.99	0.02	0.94	0.91	0.98	0.002
Precipitation (no vs. yes)	1.54	0.83	2.83	0.17	2.14	1.56	2.95	<0.001
Snow (inches)	0.83	0.64	1.08	0.16	0.92	0.85	1.001	0.053
Daylight (hours)	1.00	0.99	1.003	0.66	1.001	0.998	1.004	0.40
Distance (miles)	0.95	0.89	1.001	0.10	0.91	0.87	0.96	<0.001
Age (years)	1.01	0.99	1.04	0.39	1.03	1.01	1.05	0.01
Model QIC	814				1,617			

Table 9. Odds ratios for likelihood of men and women bicycle commuting, including SEASON.

	Women				Men			
Effect	Odds Ratio Point Estimate	95% Confidence Interval		p	Odds Ratio Point Estimate	95% Confidence Interval		p
SEASON (summer vs. spring, winter, and fall)	24.58	4.18	144.53	<0.001	11.12	3.59	20.94	<0.001
Wind speed (mph)	0.94	0.90	0.98	.009	0.95	0.91	0.99	0.01
Precipitation (no vs. yes)	1.63	0.99	2.70	0.06	2.24	1.65	3.05	<0.001
Distance (miles)	0.95	0.89	1.01	0.08	0.90	0.86	0.94	<0.001
Age (years)	ns	-	-	0.38	1.04	1.01	1.06	0.002
Model QIC	973				1,002			

CONCLUSIONS and DISCUSSION

Our results quantify effects that specific weather and seasonal characteristics can have on individuals' decision to bike commute. As might be expected, we saw strong effects of temperature, and precipitation, but also effects of wind speed and snow depth. In addition, we were able to quantify the effects of demographic and geographic factors, such as gender, age and distance to work. Likelihood of biking declined about 8% with every additional mile of commute distance. For female bike commuters, there were pronounced effects of temperature, and wind, and an overall effect of season. Similarly men's bike commuting likelihood was affected by those factors, as well as precipitation, age, and distance to work. The models with the aggregate variable SEASON demonstrated that season had a large effect on both men and women's likelihood of bike commuting, with both sexes more likely to bike in the summer than the winter or fall. Our results do not suggest that men and women respond differently to the same weather and seasonal factors. Although effects of some model factors appeared stronger for men, this was likely due to the larger sample size and thus increased statistical power for men.

This study makes a unique contribution to specification of weather influences on bicycle commuter transportation mode choice. The study engaged a panel of bicycle commuters over an extended time to assess the impact of weather conditions on their use of bicycles for travel to work. A large proportion of recruited participants provided adequate information for modeling purposes. The characteristics of participants included in the data analyses and the weather conditions recorded on study days across ten months provided good range of variation. Modeling of these data provided evidence of substantial independent effects for several major weather factors on decisions to travel to work by bicycle, including precipitation and temperature. The magnitude of observed effects of temperature and precipitation were similar to those reported by Rose et al. (2010) in their bicycle demand models for Portland, Oregon and Melbourne, Australia: 1ºC.

Contrary to expectation based on focus groups and interviews conducted for this study, in which wind was reported to not be an influence on the decision whether or not to bike commute, increases in wind speeds significantly diminished the odds of bicycle commuting. In addition, although lack of daylight in both the morning and evening hours was a commonly cited reason for not biking among participants, minutes of daylight was not a significant factor in any of the models run. Snow depth, on the other hand, had a dampening effect that might be expected when most of the panel did not typically ride bicycles in the winter months.

Although we found men more likely to bike commute than women, we saw no interaction effects in our models between gender and weather or other demographic and geographic variables, that is men and women appeared to respond similarly to adverse weather conditions. Although male bike commuters appear to be more affected than women by precipitation, this is most likely due to small sample size among women respondents and reduced statistical power as a result. Likewise, age was only a significant factor for men, although parameter estimates between men and women were similar. Commute route characteristics did not differ between men and women and none of the land use variables relating to commute route (% commercial land, % residential, and % rural) affected the likelihood of an individual bike commuting. Land use may not have been a prominent determinant in people's decision to bike commute because our study participants were already self-identified bike commuters: they had already deemed their route appropriate for biking. Ratings of work-place amenities for bicycle commuting did not affect likelihood of bike commuting either, although ratings of such amenities tended to be high among respondents. Such amenities may prove to be a more important factor among the general working public, rather those whom have already found a way to make bike commuting an option at their work place.

Notable among our results was the prominence of multi-modal bike commuting. On 15% of all person-days recorded, participants reported using more than one form of transportation on their travel to and/or from work. Further, nearly a fifth of reported bicycle commuting days were also multi-modal, most commonly used in conjunction with single occupancy motor vehicles and ride shares. These surveys results suggest that promotion and facilitation of multi-modal bike commuting presents one viable means of increasing rates bike commuting, especially among those people who already identify as bike commuters. People may be more amenable to biking to work if they are able to supplement their ride with other forms of transport, reducing their exposure to adverse weather conditions and potentially avoiding or mitigating issues such as icy roads or reduced amounts of daylight. Easy access to other forms of transportation such as personal vehicles and transit may allow bike commuters to avoid dangerous portions of road or reduce overall commuting time during the winter months.

The important role of weather in bicycle commuting presents several challenging barriers to wider use of non-motorized commuting. However, the wide range of weather through which an appreciable number of study participants used their bicycle must also be considered positive in that bicycling was feasible for workers with a broad range of personal characteristics. The results suggest that policy measures to increase commuter cycling season be aimed at research to learn more about how cyclists safely address adverse weather and daylight conditions, and that innovations in equipment and infrastructure focus on supporting bicycle commuters. Note that work place amenities did not have any effect and this study would not point to them as important factors for extending the bicycle commuting season of existing cyclists.

This study had particular strengths and weakness. Recruitment and data collection methods were relatively efficient for engaging a broadly representative bicycle commuter panel over an extended time although the requirement for electronic communications eliminated some bicycle commuters from the panel. The broad geographic areas covered by the weather data lacked local details that might influence commuting decisions. These data focused on morning commuting hours and did not account for participants who might have another type of work schedule. Moreover, weather conditions are not necessarily the same as weather forecasts which may have a different and significant impact on decisions to commute by bicycle. Based on characteristics of the Vermont population, the sample was likely low in racial and ethnic diversity.

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