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Weather Factor Impacts on Commuting to Work by Bicycle

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A Report from the University of Vermont Transportation Research Center

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Disclaimer

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1. Introduction

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 *{1,2]*. Although current levels of bicycle use as a share of travel modes is low in the U.S., it is much higher in countries with similar levels of development and weather conditions *[3]*. 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 *[4]*. Non-design factors such as the natural environment, community culture, and personal characteristics are likely also to be important in understanding decisions to use bicycles for routine travel purposes.

Prior research indicates the general importance of weather conditions on choice of bicycle travel mode, but there is a dearth of detailed information about the impact of specific factors *[5,6]*. Studies analyzing relationships between aggregate bicycle use data and community characteristics indicate that temperature and precipitation typical have significant effects, though of varying strength *[7-10]*. Similar results are reported by studies focused on variations in bicycle traffic counts under varying weather conditions *[11-15]*.

Several studies focused on individual bicycle use to better understand utilitarian travel mode choices. A survey of Swedish workers identified weather and personal factors influencing cold weather bicycle commuting *[16]*. A Canadian study linked individual bicycle use data from a cross-sectional national survey with typical weather data in metropolitan areas to assess relationships between weather, personal characteristics, and bicycle use; results included strong effects of annual days of precipitation and annual days with freezing temperatures on bicycle use *[17]*. Hanson and Hanson *[18]* analyzed detailed travel mode and weather diaries kept over a 39 day period by Swedish households; results indicated moderate correlations between bicycling to work and morning temperatures and cloud cover.

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.

2. Methods

This longitudinal study documented reports of travel to work by bicycle or other transportation mode among a panel of bicycle commuters on 28 pre-specified days over 10 months. Weather data specific to geographic location was linked to individual reports of commuting mode on these days. Precipitation, temperature, wind, and snow cover were identified as key weather conditions from prior research *[15-18]*. We focused on conditions in usual morning commuting hours, since evidence suggested these were important for transportation mode choice *[18]*. Bicycle commute distance, seasonal variation in daylight hours, and personal characteristics also were identified as factors that should be considered in the modeling of influences on bicycle commuting decisions *[11,13,16,17]*. This study was approved by the Institutional Review Board at the University of Vermont.

2.1 Participants, Setting, and Recruitment

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 $\geq$18 years, regularly working outside of the home, commute to work distance of $\geq$2.0 miles; and bicycle commuting frequency of $\geq$2 annually. Full-time students were excluded.

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. Recruitment was conducted in five communities with relatively large worker populations. The central communities and surrounding town populations ranged from 44,513 to 156,545. Central communities generally are in valleys with surrounding towns in rolling hills. 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.

2.2 Observation Schedule

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^{0} F), January (18^{0} F), April (43^{0} F), and July (71^{0} 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.

2.3 Data Sources

We conducted semi-structured individual interviews with five experienced bicycle commuters, four focus groups with male (n=12) and female (n=7) bicycle commuters, and pilot tests to develop baseline interview and survey instruments and commuting logs. The baseline interview and survey provided data on personal characteristics, and general bicycle use. The 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, mode of transportation to work, road conditions, and related information.

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).

2.4 Independent Variables

Each day logged by a participant was characterized by weather factors and amount of daylight. Distance traveled to work by bicycle and personal characteristics served as control variables.

<u>Temperature</u>. Mean temperature during 5-9 a.m. was measured in degrees Fahrenheit by the first-order weather station closest to the participant's residence.

<u>Wind</u>. Mean velocity during 5-9 a.m. was measured as miles per hour by the nearest first-order station.

Precipitation. Total amount of rainfall (or liquid value of snowfall) during 5-9 a.m. was measured in inches by the nearest first-order station.

Snow. Total depth of snow (and other frozen precipitation) on the ground was measured at 7 a.m. in inches by the nearest cooperating station.

Daylight. Amount of time from sunrise to sunset was calculated in hours and fractions thereof for each regional latitude.

Distance, Age and Gender. Usual distance traveled to work by bicycle in miles, years of age and gender categories were obtained from baseline data.

2.5 Dependent Variable

The primary outcome was a participant's report of commuting by bicycle or not on commuting days, defined as days that required a trip to a workplace outside of the home. Data were provided by commuting logs.

2.6 Data Processing and Statistical 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.

3. Results

Of the 210 individuals who responded to recruitment activities, 185 met the study criteria and completed baseline assessments. Commuting log completion varied for multiple reasons. Sufficient data for the modeling analysis were obtained from 163 individuals. All reports are based on this sample of 102 (62.6%) men and 61 (37.4%) women.

3.1 Participant Characteristics

Participants were somewhat more likely to be ≥40 years of age than younger, with similar age distributions for men and women (Table 3.1). 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 3.1 Participant characteristics for analytic sample (n=163).

	Men (n=102) %	Women (n=61) %	All (n=163) %
Age			
40 or under	41.2	41.0	41.1
40+	58.8	59.0	58.9
Education			
< 2 yr. degree	3.9	3.3	3.7
2 yr. degree	3.9	1.6	3.1
4 yr. degree	44.1	36.1	41.1
> 4 yr. degree	48.0	59.0	52.2
Health			
Excellent	48.0	45.9	47.2
Very good	41.2	45.9	42.9
Good	9.8	6.6	8.6
Fair or Poor	1.0	2.0	2.0

Most participants (81%) reported seasonal riding, that is they did not use their bicycles during the winter months, especially December-February. All reported riding in warmer months (May-September). Participants reported bicycle use for purposes other than commuting. Most prominent was recreation, with the majority reporting over 20 such uses per typical year, followed by utilitarian trips other than commuting (Table 3.2). Notably low bicycle use for training or competition was reported, indicating that most were not dedicated competitors.

Table 3.2 Proportions using bicycles for various purposes in a typical year, by gender.

Biking trips per year for:	Men (%)	Women (%)	All (%)
Recreation			
0	1.0	0.0	1.0
1-20	31.3	41.7	35.2
>20	67.7	58.3	63.8
Training/Competition			
0	60.8	71.7	64.8
1-20	23.6	16.6	21.0
>20	15.7	11.7	14.2
Utilitarian, except commuting			
0	12.8	13.6	13.0
1-20	44.1	55.9	48.5
>20	43.1	30.5	38.5

Baseline surveys also indicated that biking comprised an average of 35% of trips to work for this group. The median estimated number of annual bike commuting days was 96 (range: 5-288). For nearly half of participants the bicycle trip to work distance was 2-5 miles (Table 3.3) with a median of 6 miles and a range of 2-30. Participants reported that, on average, a bike commute required 37 minutes while a car commute required 19 minutes of travel time.

Table 3.3 Reported bicycle travel to work distances, by gender, Vermont, 2009-2010.

Distance to work	Men (%)	Women (%)	All (%)
2-5 miles	43.2	45.9	44.2
6-10 miles	29.5	34.4	31.4
> 10 miles	27.4	19.7	24.4

3.2 Trips Reported in Commuting Logs

In aggregate, the 163 participants reported on commuting modes for 103 unique calendar days during the four commuting log months. At least one participant reported biking to work on 95 of these 103 days. The total number of daily reports was 2,569 person-days of which 2,554 were days requiring a trip to work. Participants reported biking to work on 881 (34.5%) of these logged commuting days.

3.3 Weather Conditions and Daylight Hours

Weather conditions reported for the logged days matched expectations for the months included in the study (Table 3.4). The range for precipitation on these days, like the temperature and wind data, represents observations over a four hour period, accounting for the low numeric values; precipitation data were dichotomized for analytic purposes. Daylight hours for the logged days suggested that these provided a representative selection of days across the annual variation. Hours of daylight were directly correlated with early morning temperatures (r=0.80) and inversely correlated with snow depth (-0.72). Precipitation and wind were not correlated with other weather factors or daylight hours.

Table 3.4 Weather and daylight characteristics for days logged by participants.

	Range	Mean	Median
Temperature (°F)	-3.2 - 79.2	45.3	45.4
Wind (m.p.h.)	0.0 - 20.0	5.1	4.0
Precipitation (inches)	0.0 - 0.4	>0.0	0.0
Snow depth (inches)	0.0 – 23.0	2.6	0.0
Daylight (hours)	9.0 - 15.4	12.4	12.7

3.4 Modeling of Weather Impact on Bicycle Commuting

The dependent variable for bicycle commuting was regressed on the independent variables Temperature, Wind, Precipitation, Snow, Daylight, Distance, Age and Gender using the GENMOD procedure. Nearly all factors in the model had a significant independent relationship with bicycle commuting (Table 3.5); only Daylight was not significant. Interactions between Gender and other independent variables were tested but were not significant.

Table 3.5 Model parameters for regression of bicycle commuting on hypothesized factors.

Effect	Parameter Estimate	S.E.	Z	p
Temperature (°F)	0.03	0.01	5.31	<0.001
Wind speed (mph)	-0.06	0.1	-3.85	<0.001
Precipitation (no vs. yes)	0.65	0.14	4.29	<0.001
Snow (inches)	-0.10	0.04	-2.55	0.01
Daylight (hours)	-0.001	0.001	-0.57	ns
Distance (miles)	-0.80	0.02	-4.17	<0.001
Age (years)	0.02	0.01	2.62	0.01
Gender (men vs. women)	0.98	0.21	4.51	<0.001

Odds ratios showed participants were nearly twice as likely to commute by bicycle when there was no precipitation in the morning (Table 3.6). A similarly strong effect was found for Temperature, where a one degree increase raised the likelihood of biking to work by about 3%. A one mile per hour increase in wind speed decreased commuter biking likelihood by about 5%. One inch of snow on the ground reduced the likelihood of biking by about 10%. Among other factors included in the model, a one mile increase in Distance independently reduced the likelihood of commuter biking by about 8%. Men were more nearly three times more likely to bike commute than women; and each year of additional Age increased the likelihood of bike commuting by about 2%.

Table 3.6 Model parameter odds ratios.

Effect	Odds Ratio Point Estimate	95% Confidence Interval	
Temperature (°F)	1.03	1.02	1.04
Wind speed (mph)	0.95	0.92	0.97
Precipitation (no vs. yes)	1.91	1.42	2.57
Snow depth (inches)	0.90	0.84	0.98
Daylight (hours)	1.00	0.99	1.00
Distance (miles)	0.92	0.89	0.96
Age (years)	1.02	1.01	1.04
Gender (men vs. women)	2.65	1.77	3.99

4. Discussion

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.

Precipitation and Temperature appeared to be relatively strong influences on the odds of commuting to work by bicycle in this panel, consistent with other research on this topic. The odds of bicycling to work nearly doubled when there was no precipitation recorded for the morning commuting hours. Bicycle commuting decisions similarly appeared to be sensitive to average temperatures during these hours. Contrary to expectation based on focus groups and interviews conducted for this study, increases in wind speeds diminished the odds of bicycle commuting modestly. 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.

These results appear to be an advance over prior research in this area. Most studies have lacked a clear focus on the effects of well-defined weather conditions on daily decisions about bicycle commuting by individuals. The only comparable study found in the literature was based on individual log data collected in Sweden over a short period in 1971; the limited weather data in that study was reported by the participants, not from an objective source *[18]*. The strong, independent relationships reported here between individual commuting mode decisions by a diverse panel and a wide range of weather conditions should be useful for estimating bicycle traffic demand and for developing new methods to increase utilitarian bicycle use.

The bicycle commuting patterns reported in the log data generally matched expectations for amounts of bicycle commuting suggested by the baseline surveys. Participants were encouraged throughout the study to follow their normal patterns of travel to work by bicycle or otherwise, and were discouraged from making a special effort to commute by bicycle at more than their usual levels during their assigned log weeks.

Recruitment and data collection methods were relatively efficient for engaging a broadly representative bicycle commuter panel over an extended time. Cooperation from community organizations, selected workplaces, and individuals in identifying potential participants was notable. Electronic communication with participants were generally smooth during the main study. However, 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. This degree of imprecision could weaken the relationships studied. These data focused on morning commuting hours and did not account for participants who might have another type of work schedule. Based on characteristics of the Vermont population, the sample was likely low in racial and ethnic diversity.

5. Conclusions

Several weather factors had independent effects on the odds of commuting by bicycle to work among a diverse panel of adults who bike to work at least occasionally. Precipitation, temperature, wind speed, and snow depth measured in the morning commuting hours were significantly associated with bicycle commuting. These results may be useful for modeling bicycle commuting levels and for exploring methods to mitigate adverse effects of weather on bicycle commuting or to encourage greater use in more favorable conditions.

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Appendix: List of Publications and Presentations

Flynn B.S., Dana G., Sears J., Aultman-Hall L. Weather factor impacts on commuting to work by bicycle". *Preventive Medicine*, 54(1):122-124, 2012. doi:10.1016/j.ypmed.2011.11.002

Sears J., Flynn B.S., Aultman-Hall L., Dana G.S. "To bike or not to bike – seasonal factors for bicycle commuting." Accepted for publication in *Transportation Research Record*, 2012.

Sears J., Flynn B.S., Aultman-Hall L., Dana G.S. "To bike or not to bike – seasonal factors for bicycle commuting." Presented at the *Transportation Research Board Annual Meeting*, Washington DC, January 2012.