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Does Wind Discourage Sustainable Transportation Mode Choice? Findings from San Francisco, California, USA

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Abstract: This paper explores whether and to what extent wind discourages sustainable transportation mode choice, which includes riding public transportation, bicycling, and walking. A six month-long field study was carried out at four locations in San Francisco, a city that has been promoting sustainable transportation mode choice but that experiences high wind levels. It involved surveying pedestrians and on-site recording of microclimate data using various instruments. The survey adopted a mixed-method approach to collect both quantitative and qualitative data. Statistical analyses using Kruskal Wallis tests and ordinal logistic regression models identified the significant effect of wind speed on San Francisco's residents in estimating their discouragement for waiting at transit stop without shelter, bicycling, and walking. Qualitative data revealed a deeper understanding of how wind influences their sustainable transportation mode choice. This research argues for the need to adopt climate-based efforts in urban planning and policy and sheds light on the climate resilience of cities

Keywords: wind; sustainable transportation mode; mixed-method; San Francisco

1. Introduction

Firm consensus exists that transportation plays a central role in the sustainability of cities [1–5]. One transportation-related issue that engages many researchers and practitioners is the excessive dependency on automobiles in cities. They argue that this dependency intensifies traffic congestion, energy inefficiency, and air pollution, thus negatively influencing the supply and consumption of transportation, infrastructure, and land [6–10].

The discourse emphasizes the necessity of promoting sustainable transportation modes, which are defined as those "that produce fewer pollutants, use less infrastructure, and take up less public space per traveler than private automobiles" [11]. Typically, these modes include riding public transportation (e.g., bus, rail, and ferry), bicycling, walking, and other modes that would curb the use of motorized private automobiles. Research from a wide range of fields has been building up knowledge on the key factors that may increase the use of such alternative modes of transportation. These include studies focused on the built environment, economic programs, and the behavioral characteristics of transportation users.

Wind is an integral constituent of the microclimate and outdoor thermal comfort of cities, and it may affect people's everyday decision making. Since the 1970s, researchers have been looking into the impact of wind on pedestrians in urban spaces. Some measured the mechanical effect of wind on pedestrians [12–15] and proposed sets of wind speed criteria for pedestrian comfort and safety [15–22]. Others have empirically studied the effect of wind on pedestrian comfort and attendance in outdoor spaces [23–30]. What remains relatively little studied is the effect of wind on the usage of various transportation modes, especially alternative modes related to urban sustainability.

This paper examines whether and to what extent wind discourages people from making sustainable transportation mode choices in San Francisco, California, a city where wind has been a critical factor in planning and policy making since the 1980s. In this study, we focus on wind speed, which best characterizes urban wind conditions, and on the sustainable transport modes of riding public transit, bicycling, and walking, all of which require journeys taking place at least in part in outdoor spaces where users are directly exposed to wind.

We selected San Francisco for several reasons. First, the city experiences high wind levels especially between mid-spring and mid-fall, resulting in cooler summers. In July, the city's windiest month, average wind speed reaches 5.0 m/s, which is comparable to the highest monthly average of 5.5 m/s in Boston and 4.6 m/s in Chicago, two of the windiest cities in the United States [31]. Second, as a response to the high wind levels, in 1985 San Francisco became one of the first cities in North America to adopt a planning approach that mandates all new developments and additions to existing buildings in the downtown, and in several other parts of the city associated with high density or development potential as shown in Figure 1, to be designed or adopt measures to secure an acceptable wind comfort level in walking and seating areas. Third, the city frequently appears as an impactful case in studies that examine the effect of wind in cities and how urban planning can improve wind environment and enhance the comfort of public spaces [23,25,30,32–37]. Lastly, San Francisco has long been a leader in promoting urban sustainability by putting public transportation, bicycling, and pedestrians as top priorities in its policy. Understanding the effect of wind on sustainable transportation mode choice in San Francisco will benefit the planners and policy makers of the city, as well as those in other cities who seek similar goals.

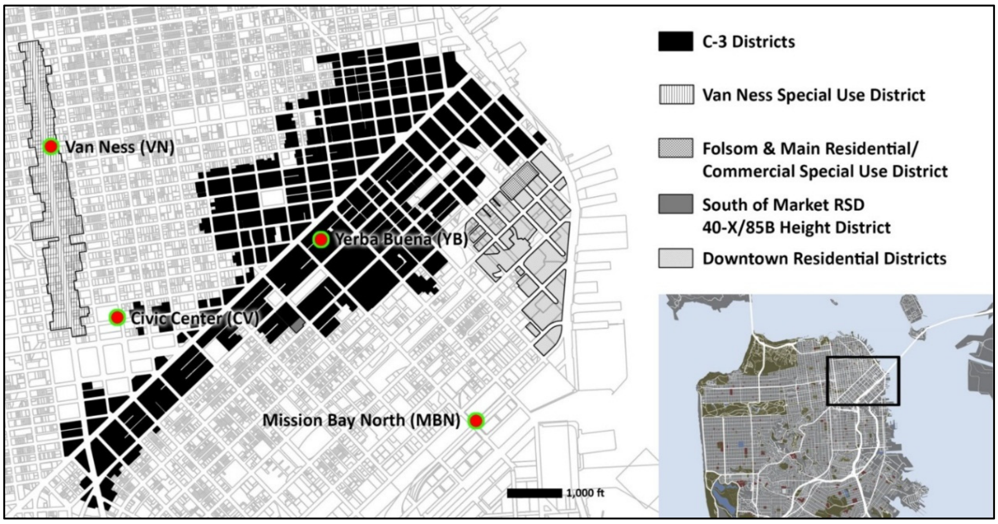

Figure 1. Five parts of San Francisco subject to wind planning and the four selected locations for field study (in red dots).

A rapidly growing body of literature explores the relationship between wind and sustainable transportation mode choice [38,39]. In most cases, wind is studied as a variable that constitutes a weather or microclimatic condition. Researchers typically approach the issue by utilizing aggregate city or regional level datasets collected from travel surveys, travel diaries, or, for bus use, electronic transport management systems. The datasets are coupled with local weather data for analysis. One group of studies has shown that higher wind speeds result in a decrease in the number of public transit trips [40–42]. Another group suggested that wind negatively impacts bicycling [43–48]. The impact of wind on walking is questionable, with some studies finding that wind significantly impacts walking and others finding no significant impact [49–52].

While the impact of wind on sustainable transportation mode choice has been getting increasing attention from researchers, there are clear gaps in the knowledge. Of concern is the kind of wind data used in most studies. Typically, wind data comes from weather data collected at a nearby weather station. This approach may be reasonable when studying the impact of temperature and humidity, since variance of these things is usually subtle at the urban or regional scale, but wind is a type of fluid whose flow and speed in any particular place in a city is influenced by numerous local factors such as the topography, buildings, bridges, signboards, and street trees. In cities like San Francisco, where numerous hills and skyscrapers characterize the urban landscape, the wind environment across the city is often very diverse. Another concern is that most studies exhibit an over-reliance on quantitative research methods. Human behavior and the decision making behind it are something that cannot easily be quantified. As such, qualitative methods, such as narrative or observation, may help planners and policy-makers unveil findings or implications that are new or complementary.

2. Methods

This research described in this paper adopted a mixed-method approach that combines quantitative and qualitative research methods. A six month-long field study to collect data was carried out in four locations of the city. It involved surveying pedestrians and on-site recording of various microclimate data by using instruments. The survey contained multiple questions directed at gathering quantitative data on how wind discourages sustainable transportation mode choice, and also included one open-ended question to acquire qualitative data.

2.1. Survey Design and Collection of Microclimate Data

To identify relevant variables for this research, we relied on two groups of sources. One is the ANSI/ASHRAE Standard 55–2010 by the American National Standards Institute and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., a widely-used industry standard used in practice and research. This standard suggests that six primary factors must be addressed when studying thermal comfort: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity [53]. The other group consists of recent studies that empirically examined people's outdoor thermal comfort in relation to various microclimatic conditions [24,27,28,54–60].

Table 1 lists the variables used in this study. The independent variables include those on microclimatic conditions (equivalent wind speed, temperature, solar radiation, and humidity), thermal history and status (metabolic rate, time spent outside in the last 1-h, and clothing insulation); those pertaining to the individual survey participant (gender, visit frequency, and visit purpose); the location at which the observations were taken and the survey administered; and the survey participant's usual use of public transit and bicycling modes of transportation. The dependent variable is the discouragement for using sustainable transportation modes. Survey participants were asked how the wind affects their decision to ride public transit, bicycle, and walk (*i.e.*, "How might the current wind level discourage you from biking?"). We used a three-point scale (no effect, slightly, and strongly) for each mode to study the discouragement. For riding public transportation, we used the proxy of waiting at an unsheltered transit stop because the possibility of waiting for a bus or streetcar in an exposed location may influence a person's transportation mode choice.

Answers given to the open-ended question ("Have you experienced any wind-discomfort in San Francisco? If yes, how did it impact your comfort level and outdoor activities?") shed light on the survey participant's experience or insight about wind and using sustainable transportation. The participants could use this question to elaborate on any part of the survey.

Table 1. List of variables for examining the impact of wind on discouragement for sustainable transportation mode choice.

Variable			Unit or Scale	Definition, Range, or Options	Collection Method
Independent Variable	Microclimatic Condition	Equivalent wind speed	m/s	Mean wind speed combined with wind turbulence	Meteorological station
		Temperature	°C	Air temperature	Meteorological station
		Solar radiation	W/m^2	Amount of solar energy received at unit area	Solar power meter
		Humidity	%	Relative humidity	Meteorological station
	Thermal history and status	Metabolic rate	met	Energy generated inside the body due to various activities (1 met = 58.2 W/m^2)	Survey
		Time spent outside in the last 1-h	minute	Degree of adaptation to the outdoor microclimatic conditions	Survey
		Clothing insulation	clo	Thermal insulation provided by garments and clothing ensembles (1 clo = 0.155 m^2·°C/W)	Recording by surveyor
	Individual	Gender	-	*1 = Female* *2 = Male*	Recording by surveyor
		Visit frequency	-	*1 = 4+ times per week* *2 = 1–3 times per week* *3 = 1–3 times per month* *4 = Rarely or first time*	Survey
		Visit purpose	-	*1 = Wait for someone* *2 = Rest or linger* *3 = Have lunch/coffee* *4 = On way to somewhere* *5 = Others*	Survey
	Location	Location	-	*1 =YB* *2 = VN* *3 = CC* *4 = MBN*	Recording by surveyor
	Usual use of sustainable transportation modes	Frequency of public transportation use	-	*1 = Rarely* *2 = Sometimes* *3 = Frequently*	Survey
		Frequency of bicycling	-	*1 = Rarely* *2 = Sometimes* *3 = Frequently*	Survey
Dependent Variable	Discouragement for sustainable transportation mode choice	Discouragement for waiting at transit stop with no shelter	-	*1 = No effect* *2 = Slightly* *3 = Strongly*	Survey
		Discouragement for bicycling	-	*1 = No effect* *2 = Slightly* *3 = Strongly*	Survey
		Discouragement for walking	-	*1 = No effect* *2 = Slightly* *3 = Strongly*	Survey

We collected most of the data by directly questioning the participants. For metabolic rate, we asked each participant to list the activities they had engaged in during the previous hour (e.g., driving: 25 min; walking: 5 min; and working at desk: 30 min) and converted the information into *met* values following the ANSI/ASHRAE Standard 55–2010 [53]. Data on some variables, such as gender and clothing insulation, came from observation. We chose not to ask the survey participants directly to avoid any discomfort and recorded our observations on a separate sheet of paper. For clothing insulation, we listed what each participant was wearing based on observation and later quantified it into *clo* values following the ANSI/ASHRAE Standard 55–2010 [53].

The four microclimate variables (equivalent wind speed, temperature, solar radiation, and humidity) were collected with two instruments frequently used in building science or urban climatology research on outdoor thermal comfort. One was a meteorological station composed of four parts: a Kestrel 4500NV Weather Tracker, rotating vane mount, tripod, and signboard. The Weather Tracker was placed on the vane mount that rotated with the wind. As shown in Figure 2, they were securely placed on the tripod, 1.5 meters above the ground level. The other instrument was an Ambient Weather SP-216 Solar Power Meter which collects solar radiation data.

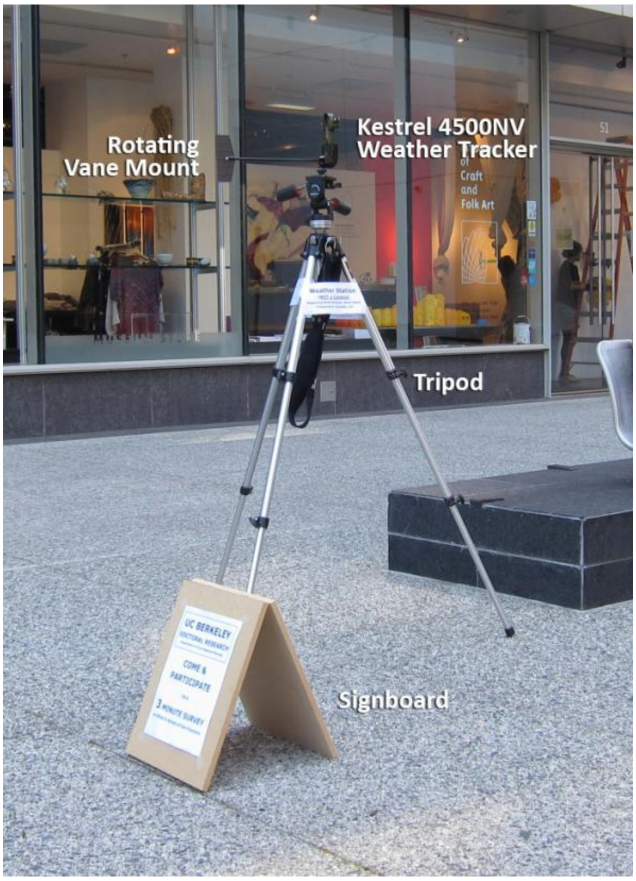

Figure 2. Meteorological station used in the field study.

We used the concept of *equivalent wind speed*, instead of wind speed, in this study. This is defined as a mean wind speed adjusted to incorporate the effects of the gustiness of outdoor wind, or turbulence intensity, on pedestrians. Equivalent wind speed was adopted in the aforementioned San Francisco's Downtown Plan and Planning Codes and has been proven to be effective in explaining the wind's effect by Hunt *et al.* [12], Jackson [13], and Lawson [19]. Equivalent wind speed is calculated by Equations (1) and (2):

$$U_{eqv} = \overline{U} \times (1 + 3I) \quad (1)$$

$$I = \frac{1}{\overline{U}} \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(U_i - \overline{U}\right)^2} \quad (2)$$

where U_{eqv} is the equivalent wind speed, $\overline{U}$ is the mean wind speed; I is the turbulence intensity, and; U_i is the wind speed measured at location i.

2.2. Field Study Locations

Field study locations were selected based on two criteria: (1) a high level of ambient wind speed, so that a wide range of wind speed can be covered; and (2) a high volume of pedestrian traffic, so that a large sample size can be acquired. Based on these criteria and observations of a number of places in San Francisco, four study locations were selected, as illustrated in Figure 1. They are: Yerba Buena Lane in front of the Contemporary Jewish Museum in Yerba Buena neighborhood (YB); the southeast corner of Van Ness Avenue and California Street intersection along Van Ness Corridor (VN); the southeast corner of P. B. Federal Building's open space (northeast corner of Golden Gate Avenue and Larkin Street intersection) in Civic Center neighborhood (CC); and the north corner of 4th and King Streets intersection in Mission Bay North neighborhood (MBN). In the rest of the paper, the locations are referred to as YB, VN, CC, and MBN, respectively. The four locations all sit on public streets or publicly accessible open spaces. All are surrounded by a mix of land uses including commercial, residential, and office in density settings above average in San Francisco.

2.3. Field Study Procedure

Field study at the four locations was carried out on weekdays from noon to 5 pm to catch both lunchtime and commuting pedestrian traffic, and from July, the windiest and second hottest month in San Francisco, through December, the least windy and coldest month, in order to encompass a wide range of meteorological conditions. After daylight saving time ended on 4 November, we carried out the study from noon to 4 pm, because it became very dark towards 4 pm, meaning that solar radiation would near zero. We did not conduct the study on wet days. A total of 26 field studies were carried out during the six-month period, seven each in YB and CC and six each in VN and MBN. Total samples of 709 were collected during these studies, out of which 701 were valid, with an average of 27 valid samples per day.

During each field study, the meteorological station was set up so as not to interfere with any pedestrian traffic or commercial activities in the vicinity. Survey administrators stood or sat approximately 2–3 meters away from the station when conducting the survey. The station automatically logged microclimate data, including wind speed, at every 10 seconds. We gave survey participants a questionnaire sheet on a clipboard with a pen and asked them to stand approximately 3 meters away from the station and not in the upwind direction, so they would not block any wind from reaching the instrument. Participants took 3 min on average to complete the survey. The equivalent wind speed for each participant was calculated based on the wind speed measured at the location during this 3-min period. Other microclimate variables used in the analysis, such as temperature, relative humidity, and solar radiation, were based on instrument readings at the beginning of the 3-min period because they remained generally constant.

3. Results

Table 2 summarizes descriptive statistics of the variables collected from the field survey and used in the analysis, as well as frequencies of the variables that are categorical or ordinal. During the six-month period, the equivalent wind speed, which was converted from raw wind speed data, ranged from 0.8 m/s to 13.1 m/s, averaging at 5.2 m/s. Temperatures were between 12.3 °C and 24.3 °C, averaging at 17.4 °C. There were slightly more men (58%) than women (42%) among the survey participants. The majority answered that they visit the survey location more than four times every week (41%), were on their way to somewhere (56%), frequently use public transportation (58%), and rarely bike (63%). With respect to discouragement for sustainable transportation mode choice, most people reported that the wind speed they felt at the time of the survey would not discourage them from waiting at a transit stop with no shelter (51%), biking (45%), or to walking outside (59%).

Table 2. Descriptive statistics and frequencies of variables.

Variable			Unit	Descriptive Statistics or Frequency			
				Min	*Max*	*Mean*	*SD*
Independent Variable	Microclimatic Condition	Equivalent wind speed	m/s	0.8	13.1	5.2	2.0
		Temperature	°C	12.3	24.3	17.4	2.4
		Solar radiation	W/m^2	6	949	238	249
		Humidity	%	46.2	94.4	69.8	11.1
	Thermal history and status	Metabolic rate	Met	0.6	4.5	1.7	0.5
		Time spent outside in the last 1-h	minute	0	60	26	20
		Clothing insulation	Clo	0.30	1.64	0.86	0.24
	Individual	Gender	-	Female: 295 (42%) Male: 406 (58%)			
		Visit frequency	-	4+ times per week: 287 (41%) 1–3 times per week: 127 (18%) 1–3 times per month: 143 (20%) Rarely/first time: 144 (21%)			
		Visit purpose	-	Wait for someone: 16 (2%) Rest or linger: 35 (5%) Have lunch/coffee: 98 (14%) On way to somewhere: 391 (56%) Others: 161 (23%)			
	Location	Location	-	YB: 239 (34%) VN: 161 (23%) CC: 183 (26%) MBN: 118 (17%)			
				Rarely	*Sometimes*	*Frequently*	
	Usual use of Sustainable Transportation Modes	Frequency of public transportation use	-	117 (17%)	117 (17%)	407 (58%)	
		Frequency of bicycling	-	442 (63%)	136 (19%)	123 (18%)	
Dependent Variable				*No effect*	*Slightly*	*Strongly*	
	Discouragement for sustainable transportation mode choice	Discouragement for waiting at transit stop with no shelter	-	357 (51%)	221 (32%)	123 (18%)	
		Discouragement for bicycling	-	318 (45%)	222 (32%)	161 (23%)	
		Discouragement for walking	-	417 (59%)	223 (32%)	61 (9%)	

Several methods of data analysis were used. For the quantitative data collected by the survey and instruments, we first used a Kruskal Wallis test to analyze the immediate impact of wind on discouragement from using each transportation mode. This was followed by estimation of the net effect of equivalent wind speed on discouragement for sustainable transportation mode choice by using ordinal (or ordered) logistic regression models, a type statistical analysis used when the dependent variable is ordinal. The qualitative data collected through the open-ended question was grouped into thematic categories.

3.1. Immediate Relationship between Wind and Discouragement for Sustainable Transportation Mode Choice

Figures 3–5 illustrate the probability distribution of equivalent wind speeds by "no effect," "slightly," and "strongly," which were the three categories of measuring discouragement for waiting at transit stop with no shelter, bicycling, and walking.

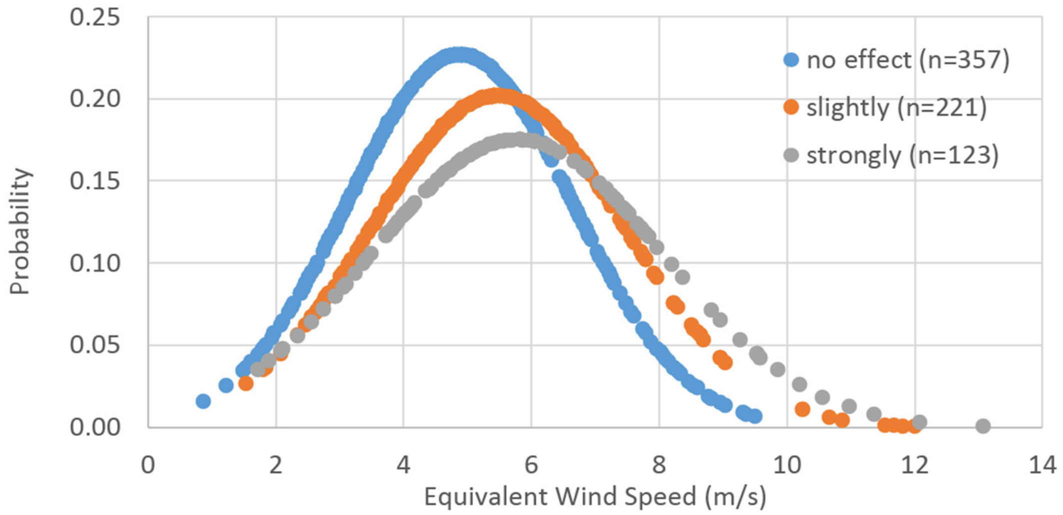

Figure 3. Probability distribution of equivalent wind speed (m/s) by discouragement for waiting at transit stop with no shelter (*N* = 701).

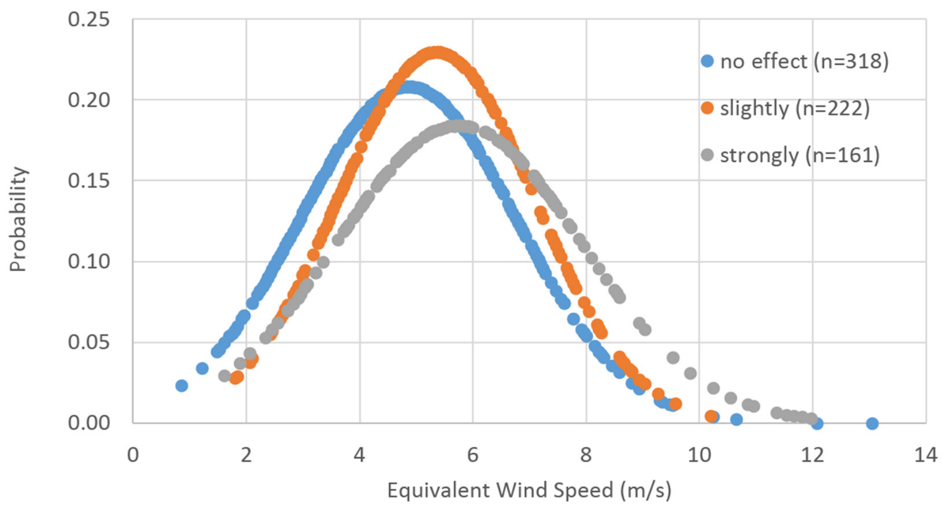

Figure 4. Probability distribution of equivalent wind speed (m/s) by discouragement for bicycling (*N* = 701).

Figure 3 shows that the mean equivalent winds speeds for "no effect," "slightly", and "strongly" were 4.87 m/s (sd = 1.75), 5.47 m/s (sd = 1.97), and 5.76 m/s (sd = 2.27) respectively, indicating that higher equivalent wind speeds are associated with being more discouraged for waiting at transit stop. The chi^2-with-ties statistic generated by Kruskal Wallis test was 18.067 (df = 2; $p < 0.001$) indicating that the differences in the mean equivalent wind speeds of the three votes ("no effect", "slightly", and "strongly") are statistically significant. Figure 4 presents a similar trend that the higher equivalent wind speeds the more people are discouraged for bicycling. The mean equivalent winds speeds for "no effect," "slightly", and "strongly" were 4.85 m/s (sd = 1.92), 5.35 m/s (sd = 1.73), and 5.75 m/s (sd = 2.16) respectively The chi^2-with-ties statistic was 21.613 (df = 2; $p < 0.001$), indicating that the differences in the mean equivalent wind speeds are also statistically significant. Figure 5 suggests that higher equivalent wind speeds do not necessarily result in increased discouragement. The mean equivalent winds speeds for "no effect," "slightly", and "strongly" were 4.94 m/s (sd = 1.76), 5.74 m/s (sd = 2.11), and 5.18 m/s (sd = 2.21) respectively, while the chi^2-with-ties statistic was 21.824 (df = 2; $p < 0.001$), indicating significance in the differences.

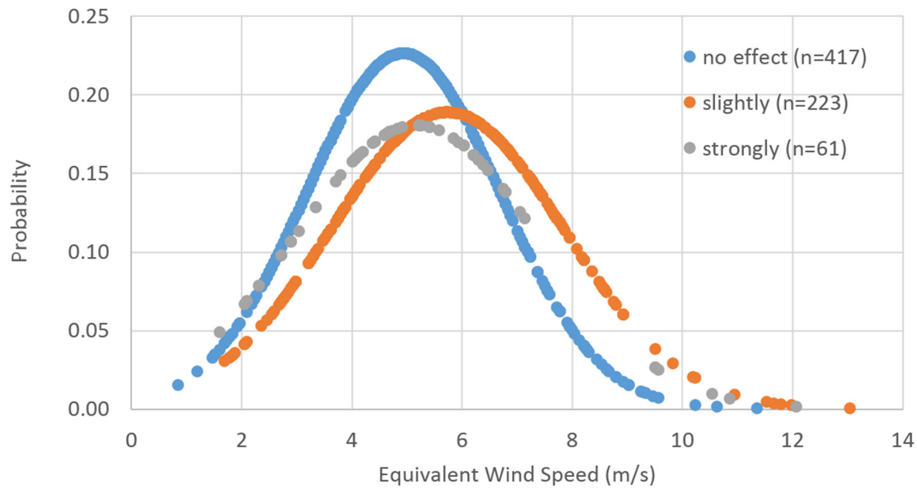

Figure 5. Probability distribution of equivalent wind speed (m/s) by discouragement for walking outside (N = 701).

In sum, it is clear that higher wind speeds relate to increased discouragement from using public transportation and bicycling. In both cases, the average equivalent wind speeds at which people feel strongly discouraged are higher than those at which people feel slightly discouraged. Likewise, those at which people feel slightly discouraged are higher than those at which people feel no effect. Discouragement from walking shows slightly different results. It may be correct to state that higher wind speeds correlate with increased discouragement overall because the average equivalent wind speed at which people feel slightly discouraged is higher than at no effect. However, the wind speed at which people feel strongly discouraged is lower than that for slightly discouraged, presenting an unclear relationship between wind and discouragement from walking.

3.2. Net Effect of Wind on Discouragement for Sustainable Transportation Mode Choice

This section reports the findings from the ordinal logistic regression models used to estimate discouragement for waiting at an unsheltered transit stop, bicycling, and walking. Other independent variables, such as those that comprise microclimatic condition, thermal history and status, individual, location, and usual use of sustainable transportation modes, as presented in Tables 1 and 3 were taken into consideration in the models.

Table 3 presents the fact that equivalent wind speed significantly affects all three dependent variables. With regard to discouragement for waiting at a transit stop with no shelter, a 1 m/s increase in equivalent wind speed would result in a 0.185-unit increase in the ordered log-odds of being a stronger discouragement category when other independent variables are held constant. In other words, for a 1 m/s increase in equivalent wind speed, the odds of the combined higher categories of discouragement category are 1.203 (= $e^{0.185}$) times higher than the combined lower categories. For example, the odds of participants being strongly discouraged are 1.203 times higher than the combined odds of them being unaffected or slightly discouraged. Similarly, a 1 m/s increase in equivalent wind speed would result in a 0.182 and 0.126-unit increase in the ordered log-odds of being a stronger discouragement category for bicycling and walking, respectively. To restate this, for a 1 m/s increase in equivalent wind speed, the odds of the combined higher categories of discouragement category for bicycling are 1.200 (= $e^{0.182}$) times higher than the combined lower categories, and for walking is 1.134 (= $e^{0.126}$) times higher than the combined lower categories. In sum, higher wind speeds make people more discouraged to wait at a transit stop with no shelter, bicycle, and walk. The summary statistics results indicate that the overall model is statistically significant.

Table 3. Estimation of discouragement for sustainable transportation mode choice using ordinal logistic regression models.

Variable		Discouragement for Waiting at Transit Stop with no Shelter		Discouragement for Bicycling		Discouragement for Walking	
		Coeff.	*Z*	*Coeff.*	*Z*	*Coeff.*	*Z*
Microclimatic Condition	Equivalent wind speed	0.185	3.99 ***	0.182	3.92 ***	0.126	2.66 **
	Temperature	−0.097	−1.85*	−0.049	−0.98	−0.065	−1.18
	Solar radiation	0.000	0.37	0.000	0.46	−0.000	−0.69
	Humidity	0.003	0.28	0.008	0.73	0.009	0.78
Thermal history and status	Metabolic rate	0.248	1.44	0.052	0.31	0.117	0.65
	Time spent outside in the last 1-h	−0.005	−1.06	−0.002	−0.41	−0.000	−0.04
	Clothing insulation	−0.206	−0.61	0.047	0.14	0.620	1.77 *
Individual	Gender [a] *(1 = Female)*	0.277	1.79 *	0.181	1.19	0.264	1.62
	Gender [b] *(0 = Male)*	0	-	0	-	0	-
	Visit frequency [a] *(1 = 4+ times per week)*	0.091	0.42	0.037	0.17	0.179	0.77
	Visit frequency [a] *(1 = 1–3 times per week)*	−0.085	−0.35	−0.118	−0.49	−0.076	−0.29
	Visit frequency [a] *(1 = 1–3 times per month)*	−0.101	−0.43	−0.282	−1.21	−0.005	−0.02
	Visit frequency [b] *(0 = Rarely/First time)*	0	-	0	-	0	-
	Visit purpose [a] *(1 = Wait for someone)*	0.002	0.01	0.308	0.86	0.317	0.84
	Visit purpose [a] *(1 = Rest or linger)*	−1.034	−1.81 *	0.226	0.45	−0.500	−0.86
	Visit purpose [a] *(1 = Have lunch/coffee)*	0.366	1.44	0.504	2.01*	0.479	1.81 *
	Visit purpose [a] *(1 = On way to somewhere)*	−0.065	−0.34	0.185	0.99	−0.207	−1.04
	Visit purpose [b] *(0 = Others)*	0	-	0	-	0	-
Location	Location [a] *(1 = YB)*	−0.032	−0.13	0.035	0.14	−0.038	−0.14
	Location [a] *(1 = VN)*	−0.589	−2.05 **	−0.375	−1.35	−0.285	−0.97
	Location [a] *(1 = CC)*	−0.298	−1.14	−0.182	−0.72	−0.383	−1.40
	Location [b] *(0 = MBN)*	0	-	0	-	0	-
Usual use of Sustainable Transportation Modes	Frequency of public transportation use [a] *(1 = Sometimes)*	−0.438	−1.85 *	−0.039	−0.17	−0.182	−0.71
	Frequency of public transportation use [a] *(1 = Frequently)*	−0.300	−1.40	0.062	0.30	0.158	0.69
	Frequency of public transportation use [b] *(0 = Rarely)*	0	-	0	-	0	-
	Frequency of bicycling [a] *(1 = Sometimes)*	0.107	0.56	0.089	0.48	−0.182	−0.87
	Frequency of bicycling [a] *(1 = Frequently)*	−0.400	−1.88 *	−0.287	−1.43	−0.070	−0.32
	Frequency of bicycling [b] *(0 = Rarely)*	0	-	0	-	0	-
Summary Statistics	*N*	701		701		701	
	Log likelihood	−680.176		−720.731		−592.718	
	Likelihood ratio Chi^2	59.78		45.49		56.46	
	p	< 0.001		< 0.001		< 0.001	
	McFadden's pseudo R^2	0.042		0.031		0.046	

[a] Dummy variable; [b] Reference category of the dummy variable. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

The models revealed additional explanatory variables, which are significant at least at the 0.10 level. They suggest that discouragement for waiting at a transit stop with no shelter is intensified by lower temperature. Men, those who visit the location to rest or linger, occasional users of public transportation, and frequent bicyclists in Van Ness were less discouraged to use public transportation by wind. The only other variable besides equivalent wind speed that was identified as significantly affecting discouragement for bicycling was when the main visit purpose was to have lunch or coffee. Lastly, those wearing lighter clothing and visiting the location to have lunch or coffee were less discouraged to walk because of wind. Visit frequency of the locations was found not to have any significant impact.

The summary statistics suggest that all three models are statistically significant. McFadden's pseudo R^2 values, which are relative to a null model in which all probabilities in a choice set are of equal share, are lower than the usual R^2 values from regular ordinary least squares regression models and may seem to be showing lower proportion of variance in the dependent variables which can be explained by the independent variables. However, unlike the usual R^2 values, it is widely recognized that there is not a definite range for McFadden's pseudo R^2 values to show excellent fit. Rather, the p values show the statistical significance of the three logistic regression models.

3.3. Findings from Open-Ended Question

The open-ended question attracted 128 survey participants to share their experience and thoughts on whether and how wind affects their use of public transportation, bicycling, and walking. Their responses ranged from several words to a few paragraphs. Specific quotes are presented below under certain topics.

Respondents complained about the excessive windiness that they experience while waiting for a bus or cable car at a stop. Some shared clear memories of such experiences by explicitly indicating the location of the stops. Exemplary responses include: "I experience too much wind whenever I am waiting for buses"; "The new bus stop at Market & Grant in the evenings provides very little protection from the wind and I get very cold"; and "Waiting for the bus is very challenging."

One decision that several people made in response to the excessive wind was to dress up, expecting that the waiting experience at the transit stop would be uncomfortable. They told us that "While waiting you end up bundling up even more or use a scarf . . . and get on the bus or train with other people who are dressed appropriately for the weather of the day."

Similarly, complaints about the wind were recorded from those who bicycle in what is one of the most bicycle-friendly cities in the country. Their responses include: "It feels like the wind is going to blow me off my bike"; "Over the past few years, I have noticed more wind in San Francisco generally. Wind makes bicycling harder when you bike into it!"; and "It is really hard to bike against the wind."

Some bicyclists came up with ways to avoid or adapt to wind when bicycling such as selecting places that are less windy or finding information of the wind prior to bicycling. Key quotes are: "I try to bike in sheltered spots"; and "As a bike commuter, I am frequently terrified by the wind. I now choose to bike based on checking wind speeds on the weather report."

With regard to walking, many people also expressed their frustration on the negative effects of wind. Their responses were like: "Makes walking to and from home rather uncomfortable. Sometimes I get something blown into my eye"; "When walking through here I often remove earrings because they are blowing around and fussing my ears"; "It has very negatively impacted my experience walking to and from my office to get coffee or go to the bank. I complain about it to my family and friends all the time!"; and "I feel like I have to struggle just to walk. Regular walking becomes a physical challenge when combating the wind."

We also found those who were trying to avoid or adapt to wind while walking. Some chose to reroute their way or move into buildings away from the wind. Others put on more clothing before walking outside. Notable responses include: "I would walk extra blocks to avoid wind"; "I avoid walking in some areas because of the strong winds"; "Got inside as quickly as possible or walked closer to the building"; and "It becomes too cold to walk outside. I have to put on a lot of layers to keep warm."

On the other hand, a substantial number of people reported that they walk because they have no other choice because San Francisco is a windy city. Some were even indifferent to the wind. Quotes from these participants were like: "Reduced my comfort level but I still walk where I need to go"; "I have to walk home from work regardless of wind"; "The wind makes walking uncomfortable, but living in San Francisco, I have no choice"; and "Not disturbed by the wind at all. Don't notice."

We attempted contextualization of the qualitative data, as shown above, in relation to the profile of the survey participant such as gender and usual use of sustainable transportation modes, but ended up finding no statistically significant relationships related to all topics. For example, those who use public transportation or bike frequently did not necessarily express negative feelings about wind while using the modes. Substantial numbers of them showed attempts to avoid or adapt, or indifference.

4. Discussion and Conclusions

In sum, the results suggest that wind discourages people from choosing sustainable transportation modes in San Francisco. Analysis of the immediate relationship between wind and discouragement for sustainable transportation mode choice clearly showed that higher wind speeds are associated with people being more discouraged to wait at transit stops and from bicycling. The relationship between wind speed and discouragement for walking presented slightly different results. The average equivalent wind speed at which people felt strongly discouraged was lower than the speed at which they felt slightly discouraged, but it was higher than the speed at which they felt no effect.

The ordinal logistic regression models identified that the effect of wind in estimating discouragement for sustainable transportation mode choice is statistically significant. The higher the equivalent wind speed, the more likely it is that people would be discouraged from riding public transportation, bicycling, and walking in San Francisco. Other significant explanatory variables for discouragement from riding public transportation included temperature, gender, rest or linger as the main visit purpose, occasional use of public transportation, frequent bicycling, and the location (VN); those for discouragement from bicycling included having lunch or coffee as the main visit purpose; and those for discouragement from walking included clothing insulation, gender, having lunch or coffee as the main visit purpose, and frequent bicycling.

The qualitative information gathered through the survey's open-ended question helped support the findings from the quantitative analysis and also presented a deeper understanding of how wind influences people's comfort and behavior, including their avoidance and adaptation, when it comes to riding public transportation, bicycling, and walking in windy conditions. Especially with regard to walking, the fact that a considerable number of people walk regardless of wind because they have to complement the unclear relationship between equivalent wind speed and discouragement for walking found earlier. It also provides a reasonable explanation for the questionable relationship as found in the literature review.

There are several shortcomings in this study. First, the survey was administered to pedestrians who were walking despite the wind conditions, which means there may have been a kind of self-selection of subjects present. Therefore, there is a chance that the sample may be biased and that the real impact may be greater than what this study found, as those who chose to drive were not surveyed. Second, the dependent variables and ways to measure them may seem subjective. Third, since the main focus of this study was on wind speed, the effect of wind direction was not recorded and studied, and yet pedestrians may find winds coming from different directions more or less annoying. Lastly, the regression models present relatively few statistically significant independent variables. However, this study contributes to the literature by identifying the significant impact of wind, and future studies may suggest alternative ways for measurement. Such methods may include carrying out a formal stated preference survey on a random sample of respondents and including additional independent variables so as to enhance the statistical significance of the independent variables used in the modeling.

Several policy suggestions derive from the research. First, the findings of this study suggest that more aggressive wind planning and design approaches should be adopted in San Francisco to protect public transit riders, bicyclists, and pedestrians from experiencing excessive winds. Streets and public open spaces should be carefully designed to reduce the negative impact of wind in order to promote sustainable transportation mode choice. Second, the city should consider establishing a longstanding effort to monitor wind in many parts of the city and to understand people's perception of wind. This would provide key information for the enactment of future wind-related policies.

This research emphasizes the need for more climate-based efforts in making cities sustainable and livable, and sheds light on the climate resilience of cities, a key current challenge. It also suggests the need for research approaches that incorporate a deep understanding of local climate conditions and seek to ascertain people's perceptions. Finally, it should be noted that although wind was found to be a major discouraging factor in San Francisco, increased wind speeds may be something that should be promoted in hot, arid climate regions, where people could benefit from breeze while waiting at a transit stops, bicycling, and walking outside.

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