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Weather is not significantly correlated with destination-specific transport-related physical activity among adults: A large-scale temporally matched analysis

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Abstract

Weather is an element of the natural environment that could have a significant effect on physical activity. Existing research, however, indicates only modest correlations between measures of weather and physical activity. This prior work has been limited by a failure to use time-matched weather and physical activity data, or has not adequately examined the different domains of physical activity (transport, leisure, occupational, etc.). Our objective was to identify the correlation between weather variables and destination-specific transport-related physical activity in adults. Data were sourced from the California Household Travel Survey, collected in 2012–3. Weather variables included: relative humidity, temperature, wind speed, and precipitation. Transport-related physical activity (walking) was sourced from participant-recorded travel diaries. Three-part hurdle models were used to analyze the data. Results indicate statistically or substantively insignificant correlations between the weather variables and transport-related physical activity for all destination types. These results provide the strongest evidence to date that transport-related physical activity may occur relatively independently of weather conditions. The knowledge that weather conditions do not seem to be a significant barrier to this domain of activity may potentially expand the universe of geographic locations that are amenable to environmental and programmatic interventions to increase transport-related walking.

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Conflicts of interest:

The authors declare there is no conflict of interest.

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Keywords

Weather; environment; physical activity; transportation

Introduction

Researchers have recently focused on the potential effects of weather and climate on physical activity. Among prior studies with adults, precipitation has generally shown a negative correlation with physical activity, while temperature is positively correlated.^{1–7} The association of physical activity with other variables, such as wind speed, relative humidity, day length and hours of sunshine, is less consistent.^{1–3,5,6}

Two major limitations characterize most of this existing research. First, authors have not examined domain-specific physical activity, i.e. recreational/leisure, occupational, household, and transportation-related activity.⁸ Instead, many have examined only total activity from all sources. Second, there has been virtually no consideration of the fact that in terms of how weather affects transport-related physical activity, the particular destination an individual is traveling to may provide important contextual information. For example, active travel to transit (e.g. bus, subway) may be relatively weather-independent, especially if the purpose is to get to work or school, whereas active travel to leisure or entertainment destinations may be highly dependent on weather conditions. Consistent with the notion that weather may differentially affect active travel depending on destination, Goodman et al referred to the possible “weather-resistance” of active commuting to school among children.⁹

To provide a more thorough examination of this topic, we conducted a novel analysis of the association between weather and active travel, separated by destination type, in adults using travel diary data from the California Household Travel Survey (CHTS) and temporally matched weather data.

Methods

Data sources

Physical activity data was derived from the CHTS.¹⁰ This survey was conducted from February 2012 to January 2013 with data collection occurring every day with no exceptions for this period, and enrolled over 42,000 households across California. Households were selected to participate using a geographically stratified address based sampling frame. All individuals within a recruited household were asked to complete an individual-level questionnaire and a one-day travel diary. Participants were asked to carry their travel diary with them on the assigned day and record their activities in real time. Surveys and travel diaries were retrieved via phone interview, online entry, or mail. If discrepancies or incomplete data were found, participants were re-contacted to complete or clarify their responses. One person per household also completed a household-level questionnaire. For this analysis, only data from adults 18 years of age and older are used. The complete CHTS dataset was downloaded from the Transportation Secure Data Center maintained by the

National Renewable Energy Laboratory in September 2014. More details on the survey sampling plan and methodology of the CHTS are available elsewhere.¹⁰

Weather data were downloaded from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information Climate Data Online website.¹¹ Weather variables were recorded hourly at weather-reporting sites across California, most of which were located at airports, including commercial airports, general aviation facilities and military airfields. All hours for all days from February 2012 through January 2013 were downloaded. To match weather data to the CHTS file, zip code centroids of participating households were geocoded; zip codes are the most granular geographic identifiers provided with the public CHTS dataset. Using a nearest-neighbor matching procedure, the closest weather-reporting site using a crow-fly (Euclidian) distance was matched to each zip code. On the basis of this match, the weather data was merged into the CHTS file, while ensuring that the weather from the appropriate station was from the same day as the household completed the travel diary. Households for which the nearest matched weather station was in excess of 20 miles away were dropped on the assumption that this was not an accurate depiction of the weather they were subjected to on their reporting day. This resulted in a loss of 7.7% of the sample.

Variables

Our primary outcome of interest is time spent in active travel to seven different destination types (transit, shopping/errands, food/eating, social, work, school, and other personal reasons), computed by summing the recorded trip duration in minutes for all walk trips to a given destination type in the CHTS dataset. Trip duration was calculated by the survey research firm on the basis of the start and stop times of each trip recorded by participants in their travel diary.

The primary independent variables of interest were daily measures of mean hourly temperature (degrees Fahrenheit), relative humidity (%), wind speed (miles per hour) and total daily precipitation (inches; includes snow and rain). Variables entered as controls on the basis of their known associations with travel behavior and physical activity included household income, assessed via 10 categorical response options; number of individuals in the household; number of household vehicles; residence type (e.g single family detached, small apartment building, large apartment building, etc.); month and day of week the household participated; age; sex; education level (coded in six categories); driver's license status; homeowner or renter; employed or not; disabled or not; foreign or U.S. born; and Hispanic or not. Total distance traveled in miles on the recorded day was used to account for the correlation between distance to destinations and travel behavior/mode selection.

Analysis

Time spent in active travel to a destination can be thought of as the result of a multi-stage process. First, an individual must decide to travel to a destination, for example, a grocery store. If they decide to travel to the grocery store, they must then decide what mode to use. If they choose an active mode, time spent in active travel will depend on many factors, such as distance traveled and how fast an individual walks. In the econometric literature, these

models are often referred to as “hurdle” models, meaning that an individual must pass a hurdle to possibly have a positive realization at the next step.¹² Consistent with the conceptual model, we use a three part model in our analyses. The first is a probit model, with the dependent variable being whether someone goes to a particular destination or not. The second is also a probit model, with the dependent variable being whether someone uses an active mode (walking) or not to get to a particular destination, among those who go to the destination in the first place. The third part is a gamma regression model, with the dependent variable being minutes spent in active travel among those who actively travel to a particular destination. Models were estimated separately for each of the seven destination types.

Interpretation of the correlation between independent variables and the primary outcome of interest, minutes spent in active travel, requires a simultaneous consideration of all three model results. This is accomplished by “stacking” the estimates from all three models to compute marginal effects. All models include cluster robust standard errors to account for the fact that more than one individual per household could participate. Analyses were conducted in Stata V13.1 (StataCorp, LP, College Station, TX). Replication code is available at github.com/durandca

Results

Included in this analysis were 65,905 individuals. Survey-weighted participant characteristics are noted in table 1. Average marginal effects for the destination-specific analyses of weather and transport-related physical activity are presented in table 2. These estimates are interpreted in the usual way: the expected change in the dependent variable, on average, per unit change in the independent variable. Examining these estimates, it is clear that in general, the weather variables are not strongly correlated with time spent in transportation-related walking. Of the statistically significant correlations, the strongest appears to be the one between precipitation and walking to school, such that for each one inch increase in precipitation during the day the participant was recording their travel, total minutes spent walking to school decreased by 0.06 minutes, on average. Even extrapolating this result to an extreme rain event of 10 inches during the travel day, this would imply that time spent walking only decreases by just over half a minute, on average. Other marginal effects were similarly weak and/or non-significant.

Conclusions

This analysis represents, to our knowledge, the largest, most comprehensive assessment of the association between weather and transport-related physical activity in adults to date. Our results indicate that weather is only weakly correlated with walking to specific destinations. Contrary to the possibility we noted in the introduction that transport-related physical activity to some destinations may be more weather-resistant than to others, the correlations between transport-related physical activity and the four weather variables largely did not vary across destination types; all the marginal effects were either substantively or statistically insignificant. In this respect, the results are consistent with the literature indicating no association between weather and active travel to school by children.^{13–15} The fact that we found similar results among adults to a wide variety of destinations suggests that

weather simply is not an especially salient feature in terms of transport-related physical activity.

Perhaps the greatest value in analyses of weather and physical activity is in understanding if weather represents a “gatekeeping” characteristic, in the sense that unless meteorological conditions are favorable, an individual will not engage in transport-related activity. Our results, however, suggest that weather does not serve this gatekeeping role and is perhaps not as significant a barrier to transport-related physical activity as previously suggested. This is important, as it indicates that strategies to promote active travel and modifications to the built environment that may encourage greater transport-related physical activity should not necessarily be restricted to areas with generally favorable climates for outdoor activities.

One caution in interpreting our data concerns the possible role of weather extremes in affecting physical activity. A 2011 study by Badland et al in Perth, Australia, found insignificant correlations between weather variables and domain-specific physical activity, similar to our results.¹⁶ The authors attribute these results to the stable, temperate climate in the Perth region, and conclude that in regions such as this, weather may not be an important determinant of physical activity. This implies that greater weather extremes may be necessary to influence physical activity. Due to the geographic context in the present study, our results both complement and contradict the conclusions of Badland. While many regions of California, particularly the coastal regions, experience relatively temperate climates, others regions are characterized by the extremes of major winter snow and summer desert heat (see fourth column, Table 1). The CHTS was designed to capture data every day of the year from across the entire state. So while the overall climate of California is temperate (and thus our results are consistent with Badland’s), extreme weather was nevertheless represented in the weather patterns the CHTS participants were subjected to, and yet we still found no significant correlations (thus contradicting Badland’s conclusion). Regardless, we agree with Badland’s assertion that the extent to which weather may or may not affect physical activity should be considered in light of the specific climate context of the region under study.

Several limitations should be noted. The CHTS only captures one day of travel data per participant; multiple days would be preferable. Also, we are relying on the self-reported travel diary data to make inferences about transport-related physical activity; we are not able to confirm these data via tracking devices such as a GPS logger or accelerometer, and no data were collected using validated instruments specifically designed to ascertain domain-specific activity. Nonetheless, the benefit of the travel diary data is the rich contextual information, such as destinations traveled to, that allow us to conduct this analysis in the first place. We also cannot rule out some degree of misclassification in terms of linking weather data to individual travel patterns. This study was characterized by several strengths. First, we matched weather data based on both time and geography. Second, the large CHTS data set represents a wide variety of individuals, travel patterns, and weather variation, giving our results a great deal of generalizability. Third, our analytic methods properly account for the complex way that weather could influence active travel.

In sum, weather should not be regarded as, *prima facie*, a barrier to implementing programs and policies designed to encourage active travel.

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Highlights

- Weather variables were not significantly correlated with time spent in active travel
- It is possible that weather does not act as a “gatekeeper” to active travel
- Programs/policies to encourage active travel should not be limited to temperate areas

Table 1

Descriptive Statistics. Data from 2012–3 California Household Travel Survey. Weighted N=21,935,704

Variable	Mean or Percent	Standard Error of Mean	Weather interquartile range (Lower extreme, upper extreme)
Mean Hourly Relative humidity (%)	62.337	0.153	49.524–76.367 (4.889,100)
Daily Precipitation (Inches)	0.033	0.001	0–0 (0–30.99)
Mean Hourly Wind speed (Miles per hour)	5.256	0.026	3.077–6.640 (0, 31.724)
Mean Hourly Temperature (Fahrenheit)	62.141	0.092	3.722–69.458 (–5.44, 104.652)
Household size	3.363	0.016	
Age (years)	47.194	0.124	
Vehicles in household	2.091	0.012	
Total miles traveled on travel day	33.034	1.009	
Month of data collection			
January	0.104		
February	0.099		
March	0.090		
April	0.066		
May	0.062		
June	0.049		
July	0.101		
August	0.094		
September	0.093		
October	0.088		
November	0.080		
December	0.076		
Homeowner or renter			
Renter	0.278		
Homeowner	0.722		
Gender			
Female	0.525		
Male	0.475		
Hispanic			
No	0.678		
Yes	0.322		
Born in U.S.			
No	0.280		
Yes	0.720		
Driver License			
No	0.141		
Yes	0.859		

Variable	Mean or Percent	Standard Error of Mean	Weather interquartile range (Lower extreme, upper extreme)
Employment Status			
No	0.433		
Yes	0.567		
Disability Status			
No	0.908		
Yes	0.092		
Education			
Less than high school	0.110		
High school graduate	0.220		
Some college	0.186		
Associates/technical degree	0.102		
Bachelor's degree	0.227		
Graduate degree	0.155		
Residence Type			
Single-family detached	0.720		
Single-family attached	0.080		
Mobile home	0.026		
2-4 unit apartment building	0.045		
5-19 unit apartment building	0.063		
20 or more unit apartment building	0.065		
Travel Diary Day of Week			
Monday	0.131		
Tuesday	0.143		
Wednesday	0.148		
Thursday	0.148		
Friday	0.142		
Saturday	0.141		
Sunday	0.147		
Household Income			
\$0-\$9,999	0.050		
\$10,000-\$24,999	0.148		
\$25,000-\$34,999	0.106		
\$35,000-\$49,999	0.135		
\$50,000-\$74,999	0.159		
\$75,000-\$99,999	0.134		
\$100,000-\$149,999	0.124		
\$150,000-\$199,999	0.078		
\$200,000-\$249,999	0.033		
\$250,000 or more	0.034		

Table 2
Average Marginal Effects Relating Weather Variables to Destination-Specific Transport-Related Physical Activity (minutes/day). N=65,905

	Destinations						
Weather Variables	Social	Other personal	Work	Transit	Shopping	Food	School
Relative Humidity (%)	0.0001 (0.0010)	-0.0001 (0.0018)	0.0038* (0.0009)	0.0056* (0.0011)	0.0026* (0.0013)	0.0017* (0.0008)	0.0003 (0.0003)
Precipitation (Inches)	0.0423 (0.0960)	0.140 (0.146)	-0.0854 (0.0682)	-0.0373 (0.0728)	0.0463 (0.0787)	-0.0710 (0.0490)	-0.0633* (0.0314)
Wind Speed (Miles per hour)	0.0054 (0.0039)	0.0153* (0.0069)	0.0108* (0.0038)	0.0137* (0.0044)	0.0160* (0.0044)	0.0109* (0.0031)	-0.0025 (0.0017)
Temperature (Fahrenheit)	-0.0046* (0.0023)	-0.0069 (0.0040)	-0.0060* (0.0026)	0.0054* (0.0025)	-0.0039 (0.0026)	-0.0018 (0.0016)	0.0001 (0.0009)

Standard errors in parentheses;

* p < 0.05; Data from 2012-3 California Household Travel Survey.