





REPORT 20-11

**THE GEOGRAPHIC DISPARITIES IN  
TRANSPORTATION-RELATED PHYSICAL ACTIVITY IN THE  
UNITED STATES: AN ANALYSIS OF THE 2017 NHTS DATA**

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## EXECUTIVE SUMMARY

Research on the relationship between urbanicity and physical activity has yielded mixed results, despite many studies consistently showing that residents tend to undertake more transportation-related physical activity in a more urban environment. The purpose of this study is to examine the geographic disparities in transportation-related physical activity at finer geographic scales in the entire nation, with and without controlling for the built and social environment at the neighborhood level.

This study takes advantage of several new questions that were added to the 2017 National Household Travel Survey (NHTS) regarding people's physical activity and their walking and bike trips that were *strictly* for exercise. Unlike previous studies that adopted a dichotomous urban–rural variable, this analysis categorizes residents into eight geographic locations: four in large metropolitan areas (downtown, inner-ring suburb, mid-ring suburb, and outer-ring suburb), two in small metropolitan areas (urban and rural), and two in non-metropolitan areas (urban and rural). The researchers conducted both descriptive and modeling analyses to evaluate the intra- and inter-metropolitan patterns of physical activity and active travel in the United States. The researchers also differentiated walk and bike trips that were *strictly* for exercise from walk and bike trips undertaken for other purposes

This study shows that the relationship between urbanicity and physical activity demonstrates a flat U-shape. Residents were more physically active when they lived in areas from the two ends of the urbanization spectrum: inner cities and inner suburbs of large metropolitan areas and the rural parts of non-metropolitan areas. Suburbanites, particularly mid-ring and outer-ring suburbanites, walked the least. The geographic pattern holds regardless of the inclusion of neighborhood characteristics in the models. There is very slight geographic variation in the weekly rates of walking and bike trips that are strictly for exercise. There is much more variation of the weekly rates of walk and bike trips that are undertaken for non-exercise purposes.

Walkers and cyclists in the eight different geographic locations reported different infrastructure and safety barriers that kept them from walking and biking more. For cyclists in the central cities of large metropolitan areas and cyclists in non-metropolitan areas, a lack of nearby paths or trails was the prominent infrastructural barrier to biking more. For suburbanites, a lack of nearby parks seemed to be a more prominent barrier to biking more. No matter which geographic location they lived in, walkers consistently reported no sidewalks or sidewalks in poor condition as the most prominent barriers to walking more. The sidewalk issue was more serious for walkers in suburbs and the urban parts of small metropolitan areas than for walkers in other locations. Insufficient lighting at night was consistently reported as the most prominent safety barrier to walking more in various geographic locations.

The findings from this study contribute to evidence-based planning of active transportation and public health interventions. Suburban areas in large metropolitan areas seem to be the least physically active places and have the largest potential for improvement. Even incremental improvements in suburbs will generate huge public health benefits, given that more than half of Americans live in suburbs. Specifically, addition to or improvement of the quality of sidewalks in suburban neighborhoods seems to be a promising strategy, given

that suburban walkers reported no sidewalks or sidewalks in poor conditions as the most prominent barriers that keep them from walking more. Improving street lighting seems to be a promising strategy to encourage more walking in urban, suburban, and rural areas. Traffic calming and good lighting at night are two potentially effective tools to encourage more biking in urban and rural areas, respectively. Rural residents take more walks outside than mid-ring and outer-ring suburbanites. Most extant studies of active travel have focused on urban and suburban residents. Our understanding of rural residents' active travel and physical activity is limited. More research needs to study how rural residents travel in non-motorized modes and how they manage to take more walking trips than mid-ring and outer-ring suburbanites.

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## I. INTRODUCTION

Research has revealed significant geographic disparities in the prevalence of chronic diseases such as overweight, obesity, and diabetes.<sup>1</sup> It is widely recognized that physical inactivity is a major cause of chronic diseases<sup>2</sup> and physical exercise is a principal intervention for the prevention thereof.<sup>3</sup> However, it is unclear whether the geographic health disparities are a result of differing levels of physical activity in different geographic locations.<sup>4</sup> On the one hand, numerous studies consistently showed that people are more likely to choose active travel modes such as walking and biking in urban environments with higher levels of density and mixed land use as well as better infrastructure for non-motorized travel.<sup>5</sup> On the other hand, studies of the relationship between urbanicity and physical activity have yielded mixed results.<sup>6</sup> The purpose of this study is to examine the geographic disparities in transportation-related physical activity in the United States by utilizing a nationally representative survey, the 2017 National Household Travel Survey (NHTS).<sup>7</sup>

This study takes advantage of a few new questions that were added to the 2017 NHTS to collect information about people's physical activity in a typical week and their walk and bike trips that were strictly for exercise in the past seven days. The researchers also obtained access to the restricted version of the 2017 NHTS data set, which allowed the researchers to locate the home addresses of survey respondents at the Census block group level. The researchers conducted both descriptive and modeling analyses to evaluate the intra- and inter-metropolitan patterns of physical activity and active travel in the United States.

This study is different from previous studies in several ways. Most existing studies of transportation-related physical activity relied on survey data that were collected at local levels. The geographic limitation of these data prevented researchers from identifying inter-regional variation of active travel in the entire nation. Many of these studies adopted a dichotomous urban–rural variable to represent geographic patterns, ignoring the heterogeneity within urban and rural areas. Moreover, many travel survey data were collected through a single-day travel diary because multiple-day travel surveys were expensive to carry out. Research showed that non-motorized trips tend to demonstrate large day-to-day intra-personal variation and a single-day survey may not be able to reveal accurate trip frequency information from non-motorized travel modes.<sup>8</sup> The 2017 NHTS data is a nationally representative sample that is uniquely suitable to analyze the geographic patterns of active travel and physical activity across multiple geographic scales in the entire nation. The large sample size and the authors' access to the restricted data allowed for movement beyond the urban–rural dichotomy and facilitated analyses at finer geographic scales. Further, the 2017 NHTS asked respondents how many walk and bike trips they took in the past seven days. The seven-day period is long enough to capture the walk and particularly bike trips that were undertaken by infrequent walkers and cyclists.<sup>9</sup> More importantly, the survey asked respondents how many walk and bike trips they took in the past seven days strictly for exercise. To the best knowledge of the research team, few national survey data sets specifically identify walk and bike trips that are *strictly* for exercise.

The remainder of the paper is organized as follows. The authors review relevant literature in the next section. Section 3 introduces the data and research methods. Section 4 reports analysis results. Section 5 is a concluding section.

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## II. LITERATURE REVIEW

The author reviewed 19 empirical studies that explicitly included geographic disparities in physical activity in their research questions. All of them were published after 1999, and 11 of them were conducted in the United States. Half focused on general physical activity, and the other half concentrated on transportation-related physical activity, mainly walking. Table 1 presents a summary of these studies.

Some of these studies reported similar or no differences in the amount of physical activity between urban and rural residents. For example, a study by Tribby and Tharp is one of the few existing studies that used the 2017 NHTS data to compare weekly bicycling rates in urban and rural areas of seven density categories.<sup>10</sup> Their analysis showed that in the United States, urban and rural residents were not statistically different in terms of their weekly use of bicycles, for all purposes or for exercise only. Carlson and colleagues analyzed the 2015 National Health Interview Survey data in the United States.<sup>11</sup> Their analysis showed that in the United States, urban and rural residents spent similar amount of time on walking. A study in Scotland showed that urban residents undertook more active travel than rural residents but the difference was mainly due to their different demographics.<sup>12</sup> Two national studies in Australia suggested that a similar group of variables could predict the amount of physical activity that people undertook regardless of where they lived.<sup>13</sup> A study in Queensland, Australia found that achieving the recommended amount of physical activity did not vary by geographic location within the region.<sup>14</sup>

Other studies found significant geographic differences in physical activity. Among these studies, most of them showed that urban residents were more physically active. A study of youth in three middle schools in southern states in the United States showed that rural youth undertook less moderate-to-vigorous physical activity than urban youth.<sup>15</sup> A national study of American adolescents also showed that among the adolescents living in suburbs, those in older neighborhoods were more physically active than those in newer neighborhoods.<sup>16</sup> Martin and colleagues analyzed the 2000 Behavioral Risk Factor Surveillance System (BRFSS) data and found that urban residents undertook more physical activity than residents in rural areas and the urban–rural difference in physical activity was stronger in southern states.<sup>17</sup> Parks et al. compared low-income residents in urban, suburban, and rural areas in the United States.<sup>18</sup> They found that low-income residents in suburban were more likely to meet the recommendation for physical activity, while low-income residents in rural areas were the least likely to meet the recommendation. Wilcox et al. studied leisure time physical activity undertaken by women of 40 years and older in the United States.<sup>19</sup> They found that urban women were more physically active than rural women and such a difference tended to be more striking in southern states and among less educated women. At least two studies found that rural residents were (at least partially) more physically active than urban residents. Rind and Jones compared the prevalence of physical activity among 354 English local authorities.<sup>20</sup> Their study indicated that urban residents took less overall physical activity and had less energy expenditure from walking than their rural counterparts. Fan and colleagues evaluated urban–rural differences in physical activity based on a national survey data set.<sup>21</sup> Their analysis suggested that the urban–rural difference in physical activity was conditional on the measurement of the intensity of the physical activity. Rural residents took more total physical activity while urban residents took more high-intensity physical activity.

Recent studies have suggested that the urban–rural differences in physical activity might depend on individual demographic factors, activity type, and regional contexts. For example, an analysis by Carlson et al. found an urban–rural difference in weekly walking rate and that the difference varied by trip purpose and among the nine Census regions in the United States.<sup>22</sup> However, in southern states, rural residents reported fewer weekly walking trips than urban residents regardless of trip purpose. McAndrews and colleagues used the 2009 NHTS data to compare cycling prevalence among ten levels of urban–rural commute areas.<sup>23</sup> Their analysis found that, in general, urban residents rode bicycles more than rural residents. However, women and youth in rural, small, and low-density places reported more bicycle trips than their counterparts in urban places. A study of residents aged 40–65 in Brisbane, Australia showed that inner urban residents rode bicycles for transportation more than suburban and outer urban residents, but there were no differences in recreational cycling between them.<sup>24</sup> A study of physical activity levels of youth in 20 counties in North Carolina found no differences between urban and rural boys but more physical activity by rural girls than urban and suburban girls.<sup>25</sup>

In summary, previous studies of the geographic patterns of physical activity have yielded mixed and even contradictory results. Researchers recognize the importance of understanding the varied correlates of physical activity in different geographic contexts. Extant research on physical activity in rural and non-metropolitan areas, however, is very limited and often restricted to isolated geographies.<sup>26</sup> Research has consistently revealed that active travel modes of different purposes (e.g. utilitarian vs. leisure) demonstrates different trip characteristics (e.g. trip duration and length) and has different environmental correlates.<sup>27</sup> Few studies, however, have analyzed the geographic patterns of active travel that were strictly for exercise. This study partially fills these gaps by analyzing the geographic disparities of physical activity, walking, and cycling at finer geographic scales in the entire nation. Unlike previous studies that relied on one-day travel diary data, this study used the 2017 NHTS in which respondents reported 7-day physical activity. The author adopted the zero-inflated poisson model and appropriately took into account the weighting variables in the model to make sure the model results are generalizable to the U.S. population. The author differentiate walk and bike trips that were strictly for exercise from walk and bike trips for other purposes.

**Table 1. A Summary of Relevant Literature**

Author (year)	Geographic Pattern Analyzed	Activity Type	Population Group	Data Source & Sample Size	Geographic Scope
Whitefield et al. (2019)	Urban–Rural	Leisure & transportation walking	Adults (aged 18+)	2015 National Health Interview Survey (N=29,925)	United States
Tribby & Tharp (2019)	Urban areas of five density levels and rural areas of two density levels	Bicycling	Age 5+	2017 NHTS (N=237,146)	United States
Carlson et al. (2018)	Urban–Rural & 9 Census divisions	Leisure & transportation walking	Adults (aged 18+)	2015 National Health Interview Survey (N=29,925)	United States

Author (year)	Geographic Pattern Analyzed	Activity Type	Population Group	Data Source & Sample Size	Geographic Scope
Sohn et al. (2017)	4 Census regions	All types of physical activity	Men aged 18+	2000 to 2010 National Health Interview Survey (N=327,556)	United States
Olsen et al. (2017)	Urban–Rural	Active travel	Age 16+	2012–13 Scottish Household Survey (39,585 journey stages)	Scotland
McAndrews et al. (2017)	Ten levels of Rural–urban commuting area	Bicycling	Age 5+	2009 NHTS (N=285,634)	United States
Heesch et al. (2015)	Inner urban, suburb, outer urban	Transport & recreation bicycling	Aged 40–65	2007 for HABITAT (N=11,036)	Brisbane, Australia
Short et al. (2014)	Regional cities vs. regional areas	All physical activity lasted 10+ minutes	Members of AHSS panel	Data collected by author (N=756)	Australia
Moore et al. (2014)	Urban/suburb/rural	Moderate-to-vigorous physical activity	Youth (4 <sup>th</sup> –8 <sup>th</sup> grades)	Data collected by author (N=804)	20 North Carolina counties
Fan et al. (2014)	Urban areas of three levels and rural areas of two levels	All physical activity	Aged 20–75	2003–2006 Health and Nutrition Examination Survey (N=5,056)	United States
Moore et al. (2013)	Urban–Rural	Moderate-to-vigorous physical activity (MVPA)	Youth in middle school	Data collected by author via accelerometer (N=284)	3 middle schools in US south
Cleland et al. (2012)	Urban–Rural (socioeconomically disadvantaged )	Leisure-time & transport-related	Women 18–45 years old	Data collected by author (N=3,669)	40 urban and 40 rural areas in Australia
Rind & Jones (2011)	354 English local authorities	Recreational physical activity	Age 16+	2006 APS (N=363,724)	England
Duncan et al. (2009)	Metro vs. non-metro	Recreational & transportation walking	Adults	CATI survey (N=1,208)	Queensland, Australia
Nelson et al. 2006	6 types of neighborhood clusters	General physical activity	Adolescent (7–12 grades)	1994–1995 NLSAH (N=20,745)	United States
Badland & Schofield (2006)	Town size of 4 levels	walking & other physical activities	Age 16+	Data collected by author (N=7,916)	New Zealand
Martin et al. (2005)	Urban–Rural & 4 Census regions	General physical activity	Adults (aged 18+)	2000 Behavioral Risk Factor Surveillance System (N=126,824)	United States
Parks et al. (2003)	Urban/suburb/rural	General physical activity	Low-income aged 18+	Phone survey by author (N=1,818)	United States
Wilcox et al. (2000)	Urban–Rural	Leisure time physical activity	Women 40+	US Women's Determinants Study (N=1242 rural & 1096 urban)	United States

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### III. DATA AND METHODS

#### DATA

This study utilized the 2017 National Household Travel Survey (NHTS) data set. Sponsored by the Federal Highway Administration, the NHTS collected the nation's information about travel by civilian residents in all 50 states and the District of Columbia. The main survey was conducted from March 2016 through May 2017. The previous two NHTSs were in 2001 and 2009. The survey covers travel behavior of nearly all travel modes for all purposes. The 2017 NHTS included 13 'add-on' partners (states and Metropolitan Planning Organizations). The data set included a national sample of 26,000 households and 103,112 additional samples from the 13 'add-on' partners. The entire data set included information about 264,234 respondents aged five and older. The 2017 NHTS added a few new questions to probe how physically active American people were in a typical week, how many walk and bike trips they took in the past seven days, and how many of these walk and bike trips were strictly for exercise, as well as the barriers that prevented them from walking and biking more.<sup>28</sup>

The public version of the 2017 NHTS data set contains variables that describe the socio-demographic characteristics of each respondent such as age, sex, education, employment status, and household income. The researchers obtained access to the restricted version of the 2017 NHTS data set, which contains the home addresses of all respondents at the Census block group level. The data enabled the researchers to measure the social and physical environment of each respondent's neighborhood by linking the data with the 2012–2016 American Community Survey (ACS) data and the 2016 Census Longitudinal Employer-Household Dynamics (LEHD) data.

The 2017 NHTS asked two questions to understand the factors that kept walkers and cyclists from walking and biking more. These two questions were asked of self-reporters who took at least one walk or bike trip in the past seven days. The respondent could choose one or more from six potential barriers. Three of them are related to infrastructure: no nearby paths or trails, no nearby parks, and no sidewalks or sidewalks are in poor condition. The other three focus on safety: street crossings are unsafe, heavy traffic with too many cars, and not enough lighting at night.

The 2017 NHTS applied complex sampling strategies to make sure the data reflected the U.S. population as a whole. Accordingly, the applied weights provided in the data set in the descriptive and modeling analyses to correct for non-representativeness of the original raw sample. Specifically, the researchers- utilized open-source software R's "Survey" package<sup>29</sup> to take into account the sampling strategies in the descriptive and modeling analyses. The "Survey" package utilized the sampling weight and 98 replicate weights provided in the 2017 NHTS data set to calculate unbiased standard errors.

#### MEASUREMENT

The descriptive statistics of all the outcome and explanatory variables are presented in Table 2.



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## Five Outcome Variables

The analysis focused on five outcome variables that were developed based on respondents' response to the two survey questions regarding residents' physical activity. The first is a three-level ordinal variable that describe each person's level of physical activity: no or never, light or moderate, and vigorous. The other four outcome variables are count variables. They represent each person's active travel in the past seven days: 1) the number of walk trips strictly for exercise (weekly exercise walk trip rate), 2) the number of walk trips not for exercise (weekly non-exercise walk trip rate), 3) the number of bike trips strictly for exercise (weekly exercise bike trip rate), and 4) the number of bike trips not for exercise (weekly non-exercise bike trip rate). When respondents reported not taking any walk/bike trips in the past seven days, their numbers of walk/bike trips strictly for exercise were coded as zero.

## Key Explanatory Variables

To analyze the geographic patterns of the five outcome variables, the researchers first categorized respondents into three general groups: large metropolitan areas with more than a half million population, small metropolitan areas with less than a half million population, and non-metropolitan areas.

The researchers further divided large metropolitan areas into four intra-metropolitan locations: downtown, inner-ring suburb, mid-ring suburb, and outer-ring suburb. The researchers defined downtown and suburban neighborhoods based on their distances to the central business districts (CBDs). The researchers used different radii of inner cities among metropolitan areas of different sizes: one mile for metropolitan areas with a half to one million population, two miles for metropolitan areas with a population of one to two millions, and three miles for metropolitan areas with a population of more than two million. The research team identified the suburban ring in which a neighborhood is located based on the ratio between its distance to the CBD and the weighted mean distance of all neighborhoods to the CBD in that metropolitan area. Specifically, an inner-ring suburb consists of neighborhoods that are outside of downtown but within half of the weighted mean distance to the CBD; a mid-ring suburb includes neighborhoods that lie at the distances of 0.5–1.5 of the weighted mean distance to the CBD; and an outer-ring suburb consists of neighborhoods that are at least 1.5 of the weighted mean distance to the CBD.

**Table 2. Descriptive Statistics of Variables**

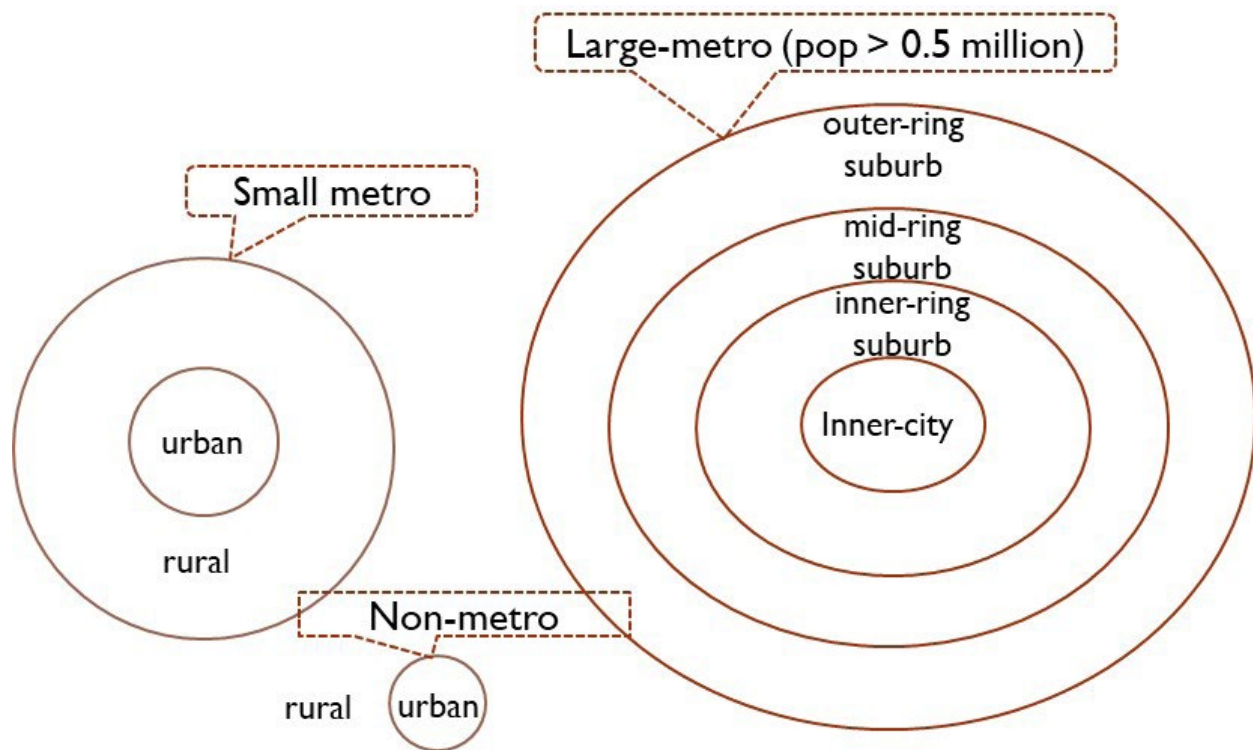
	Percent (%) (weighted)	Mean (weighted)	Sample Size (unweighted)
Physical Activity:			263611
none or rare	12.60		
light or moderate	60.63		
vigorous	26.62		
Weekly Rate of Walk Trips for Exercise		2.04	263,048
Weekly Rate of Walk Trips not for Exercise		3.56	263,409
Weekly Rate of Bike Trips for Exercise		0.21	264,090
Weekly Rate of Bike Trips not for Exercise		0.25	264,018
Sex:			263,778
male	49.07		--
female	50.93		--
Age:			263,525
5–12	10.99		
13–17	6.83		
18–24	10.37		
25–34	14.07		
35–44	14.03		
45–54	13.43		
55–64	14.46		
65+	15.82		
Household Income:			256,094
<\$25k	19.46		
\$25k–\$50k	20.52		
\$50k–\$75	16.60		
\$75–\$100k	13.21		
>\$100k	30.21		
Education:			263,791
n.a. (age<16)	12.31		
below high school	10.46		
high school	18.92		
some college education	25.05		
bachelor	18.44		
graduate degree	14.83		
Race/ethnicity:			263,140
White	61.50		
Black	12.04		
Asian	5.21		
Hispanic	17.25		
Other	4.01		

	Percent (%) (weighted)	Mean (weighted)	Sample Size (unweighted)
Employment Status:			263,984
working	44.93		
temporarily not working	2.48		
look for work/unemployed	3.53		
homemaker	6.20		
going to school	6.51		
retired	15.27		
something else	6.00		
n.a. (age<16)	15.08		
Homeownership:			263958
own	66.01		
rent	32.94		
other arrangement	1.06		
Proxy:			264,018
self-report	65.72		
proxy-report	34.28		
Vehicle Ownership (cars per driver in household)		1.05	264,018
Population Density (100,000 per squared miles)		0.07	264,018
Employment Density (100,000 per squared miles)		0.02	264,089
Mixed Land Use:			263,086
low	81.36		
medium	9.70		
high	8.94		
Median Household Income (\$10,000)		6.60	260,936
Poverty Rate		0.14	264,001
Share of White		0.64	264,013
Share of Black		0.12	264,013
Share of Hispanic		0.16	264,013
Season:			264,018
spring	24.90		
summer	25.24		
fall	25.13		
winter	24.72		
Urban size:			264,018
50k–200k	9.52		
200k–500k	10.05		
500k–1 million	8.88		
1+ million without heavy rail	20.23		
1+ million with heavy rail	24.11		
not in an urbanized area	27.21		

	Percent (%) (weighted)	Mean (weighted)	Sample Size (unweighted)
Intra- & Inter-metro Location:			263,895
large metropolitan: downtown	3.36		
large metropolitan: inner-suburb	14.48		
large metropolitan: mid-suburb	34.62		
large metropolitan: outer-suburb	15.15		
small metropolitan: urban	13.77		
small metropolitan: rural	4.13		
not in a metropolitan area: urban	6.16		
not in a metropolitan area: rural	8.26		
Census Division:			264,018
New England	4.62		
East North Central	14.59		
East South Central	5.88		
Mid-Atlantic	12.98		
Mountain	7.29		
Pacific	16.30		
South Atlantic	19.76		
West North Central	6.55		
West South Central	12.03		

For respondents in small metropolitan areas, the researchers divided them into two groups (urban vs. rural) based on urban area classification in the 2014 TIGER/Line shapefile, which are extracts of selected geographic information from the U.S. Census Bureau's database and include the boundaries of geographic areas and features in the United States. Similarly, the researchers divided non-metropolitan areas into urban and rural parts. The key geographic variable represents eight geographic locations:

1. Large metropolitan area: inner city
2. Large metropolitan area: inner-ring suburb
3. Large metropolitan area: mid-ring suburb
4. Large metropolitan area: outer-ring suburb
5. Small metropolitan area: urban
6. Small metropolitan area: rural
7. Non-metropolitan area: urban
8. Non-metropolitan area: rural



**Figure 1. Eight Geographic Locations**

### Control Variables

The researchers developed a series of control variables to measure individual-level socio-demographic characteristics and neighborhood-level social and physical environments. Specifically, individual-level variables describe each person's gender, age, race/ethnicity, income, education, employment status, homeownership, and vehicle ownership. Census block groups were used to represent neighborhoods. The researchers calculated neighborhood population and employment densities based on population, employment, and land area in each block group. Mixed land use was measured in each neighborhood by using a ratio between the number of jobs and population, then further categorizing neighborhoods into three groups based on the ratio: low, medium, and high. The researchers used five variables to describe the social environment of each neighborhood: median household income, poverty rate, and the shares of White, Black, and Hispanic population.

In addition, the researchers used a variable to differentiate self-reporters from proxy reporters. The researchers had a variable to represent the season in which the survey took place. The researchers included a categorical variable to represent urban areas of different population sizes and another categorical variable to represent the nine Census divisions.

### MODELING TECHNIQUES

The researchers estimated five sets of models for the five outcome variables. The researchers run ordered logistic regression models to decide the associations between physical activity level and geographic location after controlling for individual-level and neighborhood-level variables. The researchers chose the ordered logistic regression method because the "distances" between the three levels of physical activity (never/rare, light/moderate, and

vigorous) may not be equal.

The researchers run zero-inflated Poisson models to identify significant geographic, neighborhood, and individual variables that predict the weekly rates of walk and bike trips for exercise and non-exercise purposes. The researchers chose the zero-inflated Poisson model because the data had an excess of zero counts. For example, 93% of respondents reported zero bike trips strictly for exercise, and 94% of them reported zero bike trips for non-exercise purposes. Ordinary count models might not be appropriate when there is an excess of zero counts.

A zero-inflated Poisson regression jointly estimates two sub-models: a logit model and a Poisson model. The zero-inflated Poisson model considers two different processes that could lead a respondent to report zero walk or bike trips in the past seven days. One respondent could usually take some walk or bike trips but happened not to take any in the seven days before participating in the survey. Another respondent did not take any walk or bike trips because she did not have any interest or did not have the capability to do so (e.g. medical conditions or not owning a bicycle). Both of them reported zero trips, but they arrived at the same outcome through two different processes. The second respondent is considered a “certain zero.” The logit model predicts whether one respondent would be in this “certain zero” group. The Poisson model predicts the number of walk or bike trips for respondents who are not in the certain-zero group.

In summary, the researchers uses four major groups of variables to predict an individual resident’s physical activity: the geographic location that the resident lives in, the residents’ personal and family demographics, and the social and physical environments of the neighborhood in which the resident lives. Two modeling techniques were selected based on the statistical attributes of the outcome variables. Ordered logistic regression is used when the outcome variable represents the three levels of physical activity that a resident could have. Zero-inflated Poisson model was used when outcome variable represent the number of walking/biking trips, which contain a lot of zeros.

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## IV. RESULTS AND FINDINGS

### DESCRIPTIVE ANALYSIS

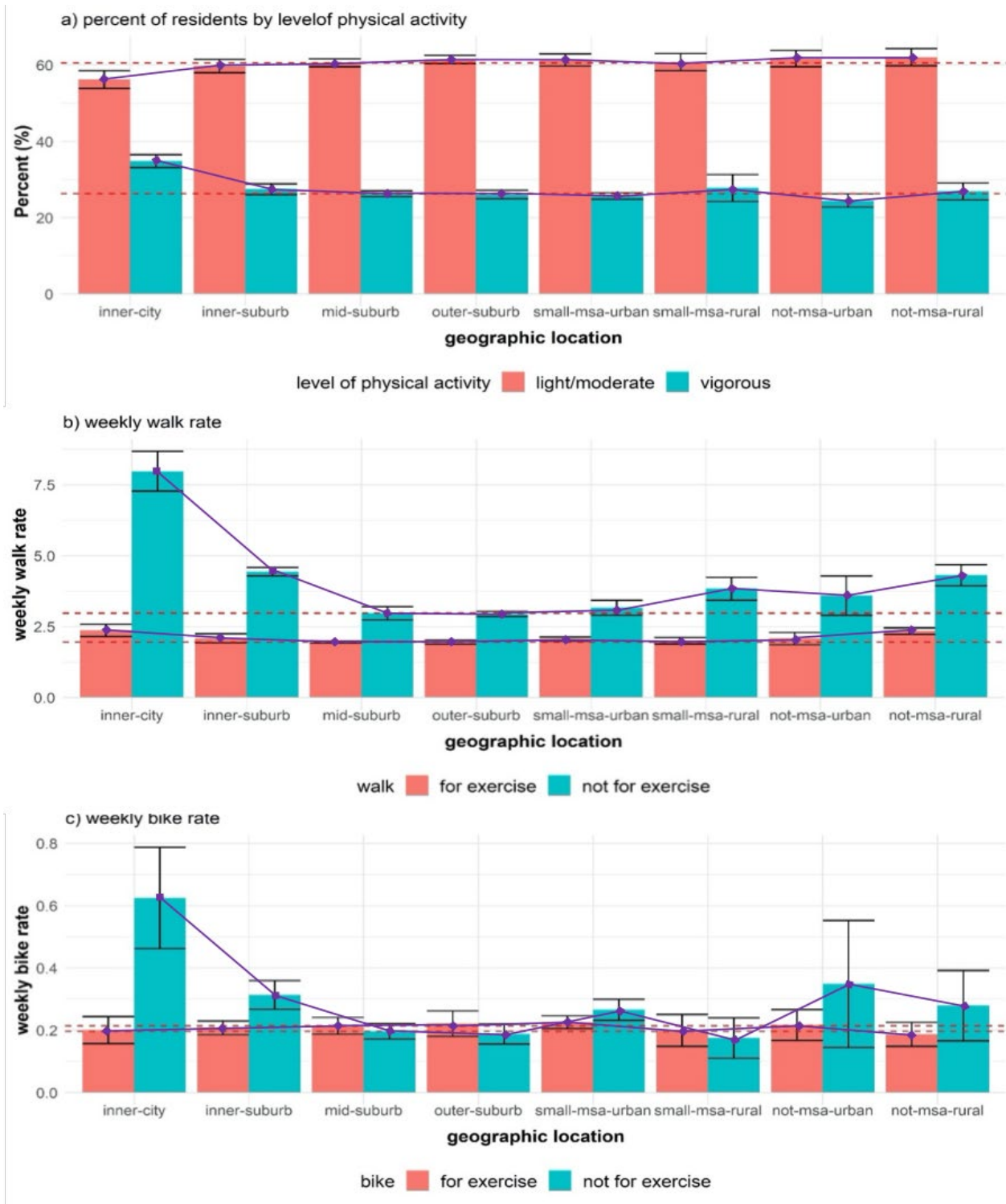
The researchers demonstrated the geographic variation of the five outcome variables (physical activity, weekly rate of exercise walk trips, weekly rate of non-exercise walk trips, weekly rate of exercise bike trips, and weekly non-exercise bike trips) among the eight geographic locations in Figure 2 (a–c). The researchers also run t-tests to decide whether a difference between two locations was statistically significant.

Figure 2a suggests that there is only slight variation in physical activity between residents in the eight geographic locations. The t-tests confirm that residents in inner cities of large metropolitan areas took significantly more vigorous-intensity physical activity but less light- and moderate-intensity activity than those in other seven locations. The differences between seven other locations outside of inner cities are not statistically significant.

There are very slight differences in the weekly rates of exercise walk trips between the eight geographic locations, as shown in Figure 2b. The t-tests show that compared to that in the mid-ring suburbs, the weekly rate of exercise walk trips is significantly higher in inner cities of large metropolitan areas, the urban parts of small metropolitan areas, and the rural parts of non-metropolitan areas. The magnitude of the differences, however, is quite small.

There is much more variation in the weekly rates of non-exercise walk trips between the eight geographic locations. Residents in inner cities of large metropolitan areas took almost eight non-exercise walks per week, which is more than double what inner-ring and outer-ring suburbanites took (about three per week). Compared with mid-ring suburbanites, the weekly rates of non-exercise walks are significantly larger for inner-ring suburbanites (4.4 per week) and rural residents in small metropolitan areas (3.8 times per week) and non-metropolitan areas (4.3 times per week). These seem to suggest that residents took more non-exercise walks when they lived in areas with the highest and lowest levels of urbanization: the inner cities of large metropolitan areas and the rural areas. Suburbanites, particularly mid-ring and outer-ring suburbanites, took the least number of non-exercise walks.

Similarly, mid-ring and outer-ring suburbanites reported the least number of bike trips for non-exercise purposes (Figure 2c). Residents in inner cities of large metropolitan areas took the largest number of non-exercise bike trips. Compared with mid-ring suburbanites, inner-ring suburbanites and urban residents in small metropolitan areas also took significantly more non-exercise bike trips. There are no significant differences in the weekly rates of exercise bike trips between the eight geographic locations.



**Figure 2. Geographic Variation of Physical Activity**

**MODELING ANALYSIS**

For each of the five outcome variables, two models were run. One base model included all the explanatory variables but not the neighborhood-level variables. This is to test whether the geographic patterns of physical activity and active travel hold after controlling for individual



characteristics. The full model included all the explanatory variables presented in Table 3. This is to test whether the geographic patterns hold after controlling for both individual- and neighborhood-level variables. The following discussions are based on the two ordered logistic regression models and the eight zero-inflated Poisson models with each Poisson model containing two sub-models. Due to space limitation, in Table 2, the researchers reported only the results of the full models that included all the explanatory variables.

It is important to note that the results of the geographic variable are largely consistent between the base models and the full models. This suggests that the geographic pattern of the five outcome variables cannot be explained by neighborhood characteristics. If a geographic variable yielded two coefficients of different significance or sign (positive/negative) in the base and full models, the researchers noted them in the following discussions. It is also worth noting that one variable may yield two coefficients of opposite signs in the two sub-models of a zero-inflated Poisson model. This is because the logit model (certain-zero model) predicts whether a person is certain to report zero trips, while the Poisson model (count model) predicts how many trips one takes in a week if he/she is not in the certain group.

The model results show that residents were more physically active when they lived in inner cities and inner-suburbs of large metropolitan areas or in the rural parts of non-metropolitan areas, after controlling for other variables. The levels of physical activity were similar among residents in the other five geographic locations. The relationship between physical activity level and urbanization demonstrates a flat U-shape. Residents were more physically active when they lived in areas from the two ends of the urbanization spectrum: the inner parts of large metropolitan areas and the rural parts of non-metropolitan areas.

There were no significant differences among the residents in eight geographic locations in terms of their tendency to certainly report zero weekly walk trips that are strictly for exercise. For residents that were not in the certain-zero group, they tended to take a greater number of exercise walks if they lived in the downtown areas of large metropolitan areas, the urban parts of small metropolitan areas, and the rural parts of non-metropolitan areas. The difference between downtown residents and mid-ring suburbanites became statistically insignificant after neighborhood-level variables were added to the model, suggesting that the difference is likely due to the variation of neighborhood environment. However, urban residents in small metropolitan areas and rural residents in non-metropolitan areas remained associated with a greater number of exercise walks than mid-ring suburbanites after controlling for neighborhood-level variables.

Residents were more likely to take non-exercise walks and tended to take a greater number of non-exercise walks when they lived in areas from the two ends of the urbanization spectrum: inner cities and inner-suburbs of large metropolitan areas and the rural parts of non-metropolitan areas. This is largely consistent with the geographic patterns of physical activity.

Geographic locations were associated with the probability that one was certain to report zero bike trips, but they were not correlated with the number of bike trips. Compared with mid-ring suburbanites, inner-city residents and urban residents in small metropolitan areas were less likely to be in the certain-zero group, and rural residents in non-metropolitan areas

were more likely to be in the certain-zero group. The difference between inner-city residents and mid-ring suburbanites, however, became statistically insignificant after controlling for neighborhood-level variables.





	DV= 3-level Physical Activity	DV=Weekly Exercise Walk Trip Rate		DV=Weekly Non-exercise Walk Trip Rate		DV=Weekly Exercise Bike Trip Rate		DV=Weekly Non-exercise Bike Trip Rate	
	Ordered Logistic Model	Zero Model	Count Model	Zero Model	Count Model	Zero Model	Count Model	Zero Model	Count Model
	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)
45–54	-0.041 (-1.005)	-0.085 (-1.785)	0.099** (5.415)	0.142** (2.980)	0.056 (1.462)	-0.022 (-0.545)	0.041 (0.500)	0.276** (4.327)	-0.064 (-0.495)
55–64	-0.027 (-0.664)	-0.108** (-4.107)	0.164** (6.113)	0.189** (3.764)	0.062* (2.255)	0.003 (0.055)	0.181 (1.439)	0.603 (4.236)	0.049 (0.480)
65+	-0.145** (-2.811)	0.160** (5.925)	0.155** (4.636)	0.349** (5.878)	0.018 (0.531)	0.628** (6.329)	0.179 (1.217)	1.225 (8.372)	-0.034 (-0.306)
Household Income									
<\$25k	-0.052 (-0.865)	-0.096* (-2.418)	0.087 (1.813)	-0.095* (-2.530)	0.087* (2.006)	-0.149 (-1.730)	0.124 (1.096)	-0.110 (-0.866)	0.093 (0.856)
\$25k–\$50k	0.019 (0.388)	0.024 (0.532)	0.029 (1.053)	0.057 (1.204)	0.045* (1.960)	-0.041 (-0.424)	-0.107 (-0.973)	-0.043 (0.403)	-0.049 (-0.492)
\$50k–\$75 (reference)	--	--	--	--	--	--	--	--	--
\$75–\$100k	0.018 (0.739)	-0.102 (-1.908)	-0.019 (-0.671)	0.064 (1.002)	-0.021 (-0.554)	-0.163 (-1.828)	-0.103 (-1.047)	0.030 (0.280)	-0.060 (-0.581)
>\$100k	0.221** (4.308)	-0.081 (-1.881)	-0.034 (-1.472)	0.025 (0.598)	0.028 (0.731)	-0.100 (-1.440)	-0.095 (-1.502)	-0.072 (-2.154)	-0.122 (-1.597)
Education									
n.a. (age<16)	-0.096 (-0.457)	0.096 (1.065)	0.048 (0.494)	-0.013 (-0.134)	-0.035 (-0.553)	-0.138 (-0.636)	0.323 (0.945)	-0.671 (-2.707)	0.194 (0.870)
below high school	-0.052 (-0.729)	0.065 (1.753)	-0.057 (-1.126)	0.035 (0.502)	-0.039 (-0.652)	-0.091 (-0.720)	-0.113 (0.382)	-0.306 (-2.885)	0.035 (0.211)
high school (reference)	--	--	--	--	--	--	--	--	--
some college education	0.171** (6.424)	-0.234** (-7.203)	-0.041* (-2.014)	-0.083* (-1.995)	-0.030 (-0.903)	-0.277** (-3.526)	-0.194 (-1.121)	-0.129 (-1.463)	-0.136 (-1.166)
bachelor	0.334** (10.547)	-0.516** (-14.950)	0.007 (0.537)	-0.235** (-5.297)	-0.103 (-1.914)	-0.635** (-10.982)	-0.305 (-1.794)	-0.439** (-3.593)	-0.065 (-0.560)
graduate degree	0.469** (14.291)	-0.643** (-14.511)	-0.005 (-0.223)	-0.403 (-8.308)	-0.079 (-1.627)	-0.759** (-7.514)	-0.250 (-1.429)	-0.789** (-7.525)	0.171 (1.445)



	DV= 3-level Physical Activity	DV=Weekly Exercise Walk Trip Rate		DV=Weekly Non-exercise Walk Trip Rate		DV=Weekly Exercise Bike Trip Rate		DV=Weekly Non-exercise Bike Trip Rate	
	Ordered Logistic Model	Zero Model	Count Model	Zero Model	Count Model	Zero Model	Count Model	Zero Model	Count Model
	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)
rent	-0.069* (-2.484)	-0.019 (-0.550)	0.035* (2.107)	-0.310 (-6.682)	0.077** (2.904)	0.141* (2.442)	0.222** (3.492)	-0.177 (-1.749)	0.161** (2.835)
other arrangement	-0.055 (-0.424)	0.162 (1.492)	0.141 (1.644)	-0.061 (-0.325)	0.074 (0.534)	-0.046 (-0.182)	0.164 (0.930)	-0.192 (-0.722)	-0.179 (-0.387)
vehicle ownership	0.058** (3.476)	0.012 (0.344)	0.012 (0.628)	0.123** (5.406)	-0.035 (-0.933)	0.000 (0.002)	-0.023 (-0.625)	0.376 (13.090)	-0.038 (-0.774)
Other control variables									
Proxy Report (yes=1)	-0.089** (-4.260)	0.210** (7.584)	-0.012 (-0.437)	0.280** (19.979)	-0.087 (-3.556)	0.138** (3.792)	0.041 (0.470)	0.093 (1.187)	-0.029 (-0.282)
Season									
spring (reference)	--	--	--	--	--	--	--	--	--
summer	0.020 (0.740)	0.016 (0.346)	0.049* (2.572)	-0.028 (-0.574)	0.048 (1.424)	-0.203** (-3.159)	0.305** (3.439)	-0.222 (-1.658)	0.121 (1.326)
fall	-0.033 (-1.549)	0.130** (4.673)	-0.000 (-0.018)	-0.089** (-2.644)	0.021 (0.405)	0.036 (0.752)	0.136* (2.437)	0.020 (0.188)	0.077 (0.747)
winter	-0.105** (-3.387)	0.341** (10.221)	-0.021 (-0.749)	0.042 (0.854)	0.020 (0.361)	0.503 (7.320)	0.067 (1.233)	0.451** (5.612)	0.050 (0.543)
Urban Size									
50k–200k	-0.050 (-0.642)	0.064 (0.772)	-0.040 (-1.576)	-0.016 (-0.174)	-0.012 (-0.240)	0.036 (0.402)	-0.057 (-0.322)	0.006 (0.034)	0.080 (0.635)
200k–500k	-0.061 (-1.387)	0.000 (0.007)	0.030 (0.777)	0.034 (0.588)	-0.099 (-1.625)	-0.056 (-0.394)	-0.032 (-0.192)	-0.130 (-0.666)	-0.054 (-0.581)
500k–1 million	--	--	--	--	--	--	--	--	--
1+ million without heavy rail	-0.107* (-2.299)	-0.053 (-0.983)	-0.001 (0.050)	0.021 (0.426)	-0.083 (-1.846)	0.051 (0.461)	-0.111 (-0.730)	0.019 (0.168)	0.099 (1.594)
1+ million with heavy rail	-0.071 (-1.644)	0.058 (0.896)	-0.023 (-0.820)	-0.114* (-2.246)	0.015 (0.378)	0.217* (2.084)	-0.232 (-1.221)	-0.275* (-2.048)	0.037 (0.372)

	DV= 3-level Physical Activity	DV=Weekly Exercise Walk Trip Rate		DV=Weekly Non-exercise Walk Trip Rate		DV=Weekly Exercise Bike Trip Rate		DV=Weekly Non-exercise Bike Trip Rate	
	Ordered Logistic Model	Zero Model	Count Model	Zero Model	Count Model	Zero Model	Count Model	Zero Model	Count Model
	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)	Coef. (z-value)
not in an urbanized area	-0.057 (-1.396)	0.005 (0.097)	0.030 (1.192)	-0.086 (-1.728)	-0.001 (-0.016)	0.018* (0.267)	-0.070 (-0.444)	0.029 (0.179)	0.005 (0.038)
Census Division									
New England (reference)	--	--	--	--	--	--	--	--	--
East North Central	-0.146* (-2.240)	0.071 (0.881)	-0.002 (-0.045)	0.193 (1.617)	-0.036 (-0.737)	-0.181 (-1.298)	-0.220 (-0.639)	-0.185 (-1.456)	0.027 (0.207)
East South Central	-0.278** (-3.292)	0.009 (0.101)	0.057 (0.716)	0.009 (0.078)	0.043 (0.435)	0.083 (0.324)	-0.546 (-1.453)	-0.115 (-0.889)	-0.129 (-0.760)
Mid-Atlantic	-0.174* (-2.202)	0.080 (1.069)	-0.006 (-0.095)	0.005 (0.048)	0.092* (2.033)	0.048 (0.259)	-0.136 (-0.431)	0.062 (0.528)	0.180 (1.185)
Mountain	0.044 (0.474)	-0.038 (-0.456)	-0.024 (-0.494)	-0.029 (-0.275)	-0.018 (-0.229)	-0.393* (-2.292)	-0.110 (-0.280)	-0.674** (-3.691)	0.080 (0.345)
Pacific	0.005 (0.046)	-0.080 (-1.002)	0.001 (0.011)	-0.041 (-0.505)	-0.045 (-0.941)	-0.223 (-1.235)	-0.418 (-1.367)	-0.463** (-4.338)	0.130 (0.980)
South Atlantic	-0.180* (-2.257)	0.045 (0.509)	0.071 (1.430)	-0.002 (-0.023)	0.129** (4.211)	-0.262* (-2.250)	-0.325 (-1.034)	-0.003 (-0.021)	0.075 (0.880)
West North Central	-0.170 (-1.702)	0.089 (0.832)	0.049 (0.691)	0.235** (2.696)	-0.011 (-0.182)	-0.172 (0.685)	-0.355 (-0.917)	-0.291** (-2.932)	-0.259 (-1.277)
West South Central	-0.117 (-1.623)	0.170* (2.010)	0.002 (0.036)	0.057 (0.506)	0.156* (2.110)	-0.025 (-0.134)	-0.291 (-0.736)	-0.226 (-1.790)	0.049 (0.301)
Intercept	--	0.673** (2.988)	1.246** (11.158)	0.467* (2.009)	2.194** (17.893)	2.917 (15.281)	1.254** (2.289)	3.816** (12.768)	1.556** (8.481)
N	261,582	249,820		250,267		250,775		250,755	

Note: \*significant at the 5% or lower level; \*\*significant at the 1% or lower level.



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## BARRIERS TO WALKING AND BIKING MORE

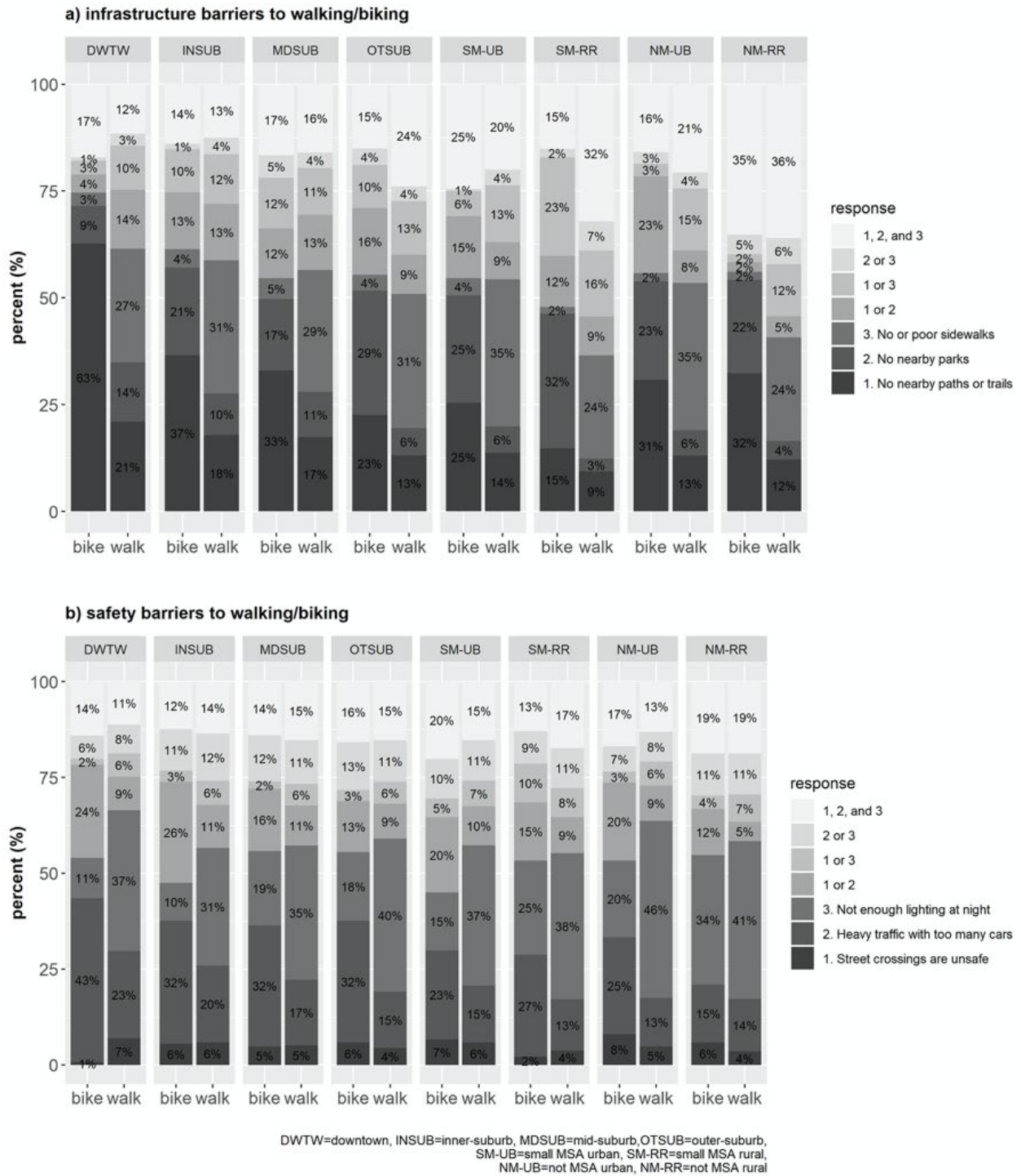
For respondents who took a walk or bike trip in the past seven days, they were asked what keeps them from walking/biking more. Respondents were given six options and they could select all that apply. The six options include: 1) no nearby paths or trails, 2) no nearby parks, 3) no sidewalks or sidewalks are in poor condition, 4) street crossings are unsafe, 5) heavy traffic with too many cars, and 6) not enough lighting at night.

Among the respondents that were eligible to answer the question “which of the following keeps you from walking more,” 38% of them reported at least one of the six factors that kept them from walking more. Among the respondents that were eligible to answer the question “which of the following keeps you from biking more,” 45% of them reported at least one of the six factors that kept them from biking more. The researchers are more interested in whether people living in the eight geographic locations reported different barriers to walking and biking more.

Figure 2a demonstrates the infrastructural barriers to walking and biking more in the eight geographic locations. The stacked bars represent the composition of respondents in each geographic location based on their responses to the survey question. It seems that no nearby paths or trails was a major barrier to biking more for residents in inner cities of large metropolitan areas and non-metropolitan areas but less of a problem for residents in suburbs of large metropolitan areas and small metropolitan areas. For suburbanites, no nearby parks seems to be a more prominent barrier to biking more.

No sidewalks or sidewalks in poor conditions was the most reported barrier to walking more in all eight geographic locations. Suburbanites in large metropolitan areas and urban residents in small metropolitan areas are more likely to report this problem as a barrier than residents in other geographic locations. No nearby paths and trails was the second most reported barrier to walking more, and residents in more central locations of large metropolitan areas were more likely to report this problem.

Figure 2b shows the safety barriers to walking and biking more in the eight geographic locations. Unsafe street crossing did not seem to be a major barrier to walking and biking more in any of the eight geographic locations. Heavy traffic was the most prominent barrier to biking more in large metropolitan areas, particularly in their central locations. Insufficient lighting at night was a major barrier to biking more only in rural areas. Insufficient lighting, however, was consistently reported as the most prominent barrier to walking more in all eight geographic locations. Heavy traffic seemed to be a moderate problem for walking and was more likely to be a problem for residents in central locations in large metropolitan areas.



**Figure 3. Barriers to Walking and Biking More**

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## V. CONCLUSION

The study analyzed the spatial disparities in physical activity, particularly transportation-related physical activity, among eight geographic locations: downtown, inner-suburbs, mid-ring suburbs, and outer-ring suburbs of large metropolitan areas, the urban and rural parts of small metropolitan areas, and the urban and rural parts of non-metropolitan areas.

The descriptive analysis found slight variation of physical activity level between the eight geographic locations. Only slight geographic variation exists in weekly rates of walk and bike trips that are strictly for exercise. There was, however, much more variation in the weekly rates of walk and bike trips that were not for exercise. Residents in the central locations of large metropolitan areas took a significantly larger number of weekly walk and bike trips for non-exercise purposes. The weekly rates of walk and bike trips for non-exercise purposes demonstrated a non-linear relationship with the level of urbanization. Residents in the mid-ring and outer-ring suburbs reported the lowest rates of weekly non-exercise walk and bike trips.

The model results generally confirmed that residents were more physically active when they lived in the areas from the two ends of the urbanization spectrum: inner cities and inner suburbs of large metropolitan areas and the rural parts of non-metropolitan areas. The geographic pattern holds after controlling for neighborhood-level variables. Furthermore, mid-ring and outer-ring suburbanites were not only more likely to report zero walk trips for non-exercise purposes and zero bike trips for both exercise and non-exercise purposes, but also tended to report a smaller number of walk trips for both exercise and non-exercise purposes. Interestingly, rural residents in non-metropolitan areas tended to report a greater number of walk trips for both exercise and non-exercise purposes than mid-ring suburbanites, even after controlling for individual-level and neighborhood-level variables. Rural residents take more walks outside than mid-ring and outer-ring suburbanites. Most extant studies of active travel focused on urban and suburban residents. There is a need for more research to understand how rural residents travel in non-motorized modes and how they manage to take more walk trips than mid-ring and outer-ring suburbanites

Walkers and cyclists in the eight different geographic locations reported different infrastructural and safety barriers that kept them from walking and biking more. For cyclists in the central cities of large metropolitan areas and cyclists in non-metropolitan areas, a lack of nearby paths or trails was the prominent infrastructure barrier to biking more. For suburbanites, a lack of nearby parks seemed to be a more prominent barrier to biking more. No matter which geographic location they lived in, walkers consistently reported no sidewalks or sidewalks in poor condition as the most prominent barriers to walking more. The sidewalk issue was more serious for walkers in suburbs and the urban parts of small metropolitan areas than walkers in other locations. Not enough lighting at night was consistently reported as the most prominent safety barrier to walking more in different geographic locations.

The findings from this study contribute to evidence-based planning of active transportation and public health interventions. The results of this study suggest a few areas in which transportation planning and policies have the potential to promote active travel and physical activity. First, providing complete sidewalks will be an effective tool to promote walking and

it will work in almost all geographic locations of different levels of urbanicity. Residents in various geographic locations consistently report a lack of sidewalks or sidewalks in poor condition as the primary barriers to walking more. Second, suburbs in large metropolitan areas seem to be the least physically active places and have the largest potential for improvement. Even incremental increases of physical activity in suburbs will generate huge public health benefits, given that more than a half of Americans live in suburbs. In addition to infrastructural barriers, heavy traffic is another primary reason why mid- and outer-ring suburbanites do not ride bicycle more. Lowering speed limits and traffic calming are thus two potential ways to encourage more biking in suburban neighborhoods. Third, in rural areas, improving street lighting and providing more parks seems to be two promising strategies to encourage more biking.

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## ABBREVIATIONS AND ACRONYMS

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ACS	American Community Survey
Coef.	Coefficient
LEHD	Longitudinal Employer-Household Dynamics
MSA	Metropolitan Statistical Area
NHTS	National Household Travel Survey
TIGER	Topologically Integrated Geographic Encoding and Referencing

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## ENDNOTES

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