Active Transportation and Health:
Predictors from Urban Design and Modeled Commuting Behavior

By

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Abstract

ACTIVE TRANSPORTATION AND HEALTH:

PREDICTORS FROM URBAN DESIGN AND MODELED COMMUTING BEHAVIOR

Maggie L. Grabow

Under the supervision of Professor Jonathan Patz
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Increases in per capita vehicle usage and associated emissions, along with decreases in physical activity, have initiated renewed examination of the ways in which our communities are developing. Automobile exhaust contains precursors to ozone and fine particulate matter, posing health risks, while dependency on car commuting also reduces physical fitness opportunities. In fact, transport-related inactivity, i.e. the use of motorized transport rather than walking and bicycling, has been linked to increased mortality and decreases in healthy life years, with the greatest impacts on chronic diseases. Recent research has begun to focus on the link between physical activity, public health, and the built environment in an effort to address the increasing rates of overweight, obesity and chronic diseases; yet, there is not as much evidence on active transportation. This dissertation attempts to fill some of the gaps in research on built environment affects on active transportation.

In the first paper, I address the individual and environmental correlates of active transportation behavior. Our findings suggest that active transportation behaviors are likely to be associated

with individuals' perceptions of their built environment, but primarily with the presence of proximal destinations, trails, and streets supportive of bicycling and walking.

In the next paper, I develop a composite "active transportation" index that includes both connectivity and proximity measures, which builds off previous walkability indices, but also includes measures of bikeability, and public transit. My findings drive future policy decisions focused on the facilitation of utilitarian transport.

Last, I examine the many air quality, physical fitness, economic, and global climate change mitigating affects of replacing short car trips with bicycle trips in the eleven largest cities in the Upper Midwest. My findings suggest that significant health and economic benefits are possible.

This dissertation offers evidence supporting a priority to transform communities so as to provide alternative transportation options to motorized vehicle use, and in favor of community investments that get people moving, such as bicycle and pedestrian infrastructure improvements and mixed-use developments.

Dedicated to the late Harris R. Grabow, my Gramps,
who appreciated the value of education more than anyone I have ever known

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Chapter 1

Introduction

Background and Significance of the Problem:

The current fossil fuel-based transportation system of the U.S. impacts human health through its contribution to air pollution, physical inactivity, motor vehicle crashes, and climate change. Transportation-related air pollutants are one of the largest contributors to poor air quality. Today asthma affects one person in twelve in the U.S., and affects nearly 27 million people. Ten million adults have been diagnosed with chronic obstructive pulmonary disease. Seven million children are asthmatic, with low-income and minority communities bearing most of the disease burden (EPA 2012). Recent estimates show that 63,000-88,000 premature deaths per year in the United States are due to fine particulate matter in the air.

Moreover, physical inactivity remains a primary contributor to the overweight or obesity of two-thirds of adults and one-sixth of children and adolescents (U.S. DHHS 2012). In fact, physical inactivity has become one of the most significant public health issues in the United States; it has been deemed one of the leading causes of mortality (Blair et al. 1996; Mokdad et al. 2004). Since 40 percent of automobile trips are less than two miles, many trips may, in fact, be easily walkable or bikeable (NHTS 2009). We can link six of the ten leading causes of death either to sedentary lifestyles, air pollution, or motor vehicle crashes, all of which are products of our increasing reliance on cars (CDC 2004). Some attribute this trend in part to automobile-oriented development that dominates suburban neighborhoods across the U.S and the U.S. Federal Transportation policies for much of the past 60 years (Doyle 2006; Handy 1996). A strong solution that would prevent these negative consequences is to promote safe alternatives to driving cars, such as public transit, bicycling and walking. However, for many reasons that range from financial or cultural to lack of infrastructure, not everyone in the United States can (or wants to) consider these health-promoting alternatives to driving.

There is increasing research evidence that the built and social environment may either provide or limit opportunities for physical activity (Brennan-Ramierez et al. 2006; Day et al. 2006; Handy et al. 2005; Moudon and Lee 2003; Suminski et al. 2008). The Healthy People 2010 and 2020 initiatives state that "individual health is closely linked to community health—the health of the community and environment in which individuals live, work, and play" (US DHHS 2010). Therefore, the extent to which the built environment supports physical activity behaviors such as walking and bicycling may have a substantial impact on human health. However, existing data still offer an unclear picture on what specific neighborhood elements, individual and family attributes, and measurement methods are most relevant in explaining physical activity differences, particularly for active transportation. Health benefits of physically active commuting are becoming more recognized; thus, examining the predictors and benefits of active transportation is an important research opportunity.

My overarching goal for this dissertation is to provide evidence for designing or retrofitting cities so that they facilitate and support active modes of transportation. I propose to meet this goal through three **Aims:**

1) To understand the perceived and environmental predictors of active transportation behavior among adults living in Wisconsin.

2) To develop an active transportation index and test its association with active transportation behaviors, BMI levels, and self-reported health in Wisconsin, and compare it to other indices of transportation (such as Walkscore).

3) To assess the health, economic, and air quality co-benefits of substituting bicycling for all short car trips (<5 miles round trip) in the 11 largest Upper Midwestern cities.

Through this work, I provide more insight and evidence to the small pool of studies that have examined predictors of active transportation. I also assist in advancing the science behind active living research by developing an active transportation index, which moves beyond existing literature to include both walkability and bikeability. Lastly, my work informs policymakers, city planners, engineers, and public health professionals of the large health, economic, and environmental dividends to be gained by making communities more bicycle and pedestrian friendly. As policymakers consider transportation-related regulations regarding Complete Streets policy, Safe Routes to School policy, and bicycle/pedestrian supporting infrastructure programs, it is especially important to differentiate the benefits of transportation-related physical activity from the other domains. Such physical activity, also referred to as utilitarian transport, can be offered as one part of the solution to the epidemic of physical inactivity.

Understanding the History Behind Built Environment and Urban Design in the United States – How it has "Shaped" Us

The built environment refers to the human constructed form and character of communities; the places where we live, work, and play (Frank et al. 2003). Understanding the history behind the built environment in the United States helps to clarify the current barriers to active transportation.

After World War II, highways began to take over the American countryside. In 1956 the Interstate Highway Act was passed, providing 41,000 miles of road linking metropolitan areas and by-passing cities at the cost of $60 billion (Frumkin et al. 2004). William H. Whyte exclaimed to Fortune Magazine in 1958, that the Federal Highway Act set out to "disperse our factories, our stores, our people, in short, to create a revolution in living habits" (qtd. in Frumkin et al. 2004). This phenomenon of often unplanned, rapid and expansive growth of greater metropolitan areas is referred to as "urban sprawl." As the cities "sprawled" into rural areas, land use transforms into a "leapfrog" low-density pattern where housing, retail stores, offices, industry, recreational facilities, and parks are kept separate from one another. Thus, necessarily, one of the direct effects of sprawl is the reliance of suburban residents on automobiles.

In 1962 the Federal Aid Highway Act was established with an incentive of 90% funding for Interstate Highway projects, requiring states to pay the remaining 10%, which would be generated through taxes on fuel, automobiles, trucks and tires (Duany et al. 2000). With the institution of the Veterans Administration mortgage program and increased mortgage insurance, even more people could afford to move to the outskirts of town where the land was less expensive, making automotive ownership affordable and public transit less desirable (Frumkin et al. 2004). By allowing people to live farther from places they work and shop, the interstate highway system transformed American communities. Thus, as highway projects took priority over streetcar maintenance, the advent of the highway system commenced the decline of mass transit presence in the United States.

The design of the transport network in the United States also changed dramatically after World War II. Abandoning the historical development patterns based on pedestrian movement, the traditional grid pattern was replaced by disconnected and winding streets designed to accommodate automobile travel. In 1948, a report issued by the American Public Health Association's Committee on the Hygiene of Housing advocated a hierarchical street classification scheme, stating that neighborhoods should be as disconnected as possible "to discourage through traffic through the neighborhood…Streets should be laid out so that no streets within the neighborhood can be used as a short cut between two points outside it…This may be accomplished by loop or dead-end streets" (Frank et al. 2003). In this hierarchical street pattern employed in the U.S. since the 1950s, streets remain deliberately ordered into a hierarchy based upon traffic movement. Major arterial roads, designed primarily for high-volume automobile traffic often without amenities for bicyclists or pedestrians hold the highest tier on the hierarchy. Local residential streets, designed to ensure a low volume of through traffic by automobiles, are at the bottom of the hierarchy (Frank et al. 2003).

Before World War II, new neighborhoods were developed with sidewalks as an essential component of a complete community. After the war, as suburban residential development densities decreased and residential areas became more isolated from services, sidewalks gradually disappeared from the design of many suburban neighborhoods. Thus, the street network went from highly connected and easy to navigate to highly disconnected and inconvenient for pedestrians.

After World War II, thought about how to design important elements of the built environment underwent a series of major changes, fueled prominently by the emergence of the automobile. Facilitated by federal state, and local policies, the compact, pedestrian-friendly city center evolved into a sprawling, automobile-centered edgeless suburb. Some may argue that the current challenge is to undo the damage from the urban exodus. However, others value the peace and tranquility of suburban and rural life. Moving forward, we can acknowledge these differences and look to policies, such as Complete Streets policies, and principles, such as Smart Growth Principles, to promote healthy and sustainable living in every community.

Understanding Environmental Determinants of Active Transportation and the Built Environment

In order to make correlations between our built environment and health, it is important to examine the environmental determinants of physical activity, and, more specifically, active transportation. We can examine the multiple realms that influence active living in the built environment, including land use mix, pedestrian infrastructure, perceived environment, safety measures, and destinations. Land use mix, especially the close proximity of shopping, work, and other non-residential land use to housing is often found to be related to greater walking or cycling among residents (Cervero 1996; Ewing and Cervero 2010; Frank and Pivo 1994). One study found that better pedestrian infrastructure, including sidewalks and street lighting, was related to greater use of active transportation, particularly for non-work trips originating from home (Cervero and Kockelman 1997). The perceived environment is how people experience their surroundings from their own perspective, and how this affects subsequent behaviors. Installation of calming devices to slow traffic, providing sidewalks for pedestrians, and assuring a safe means to cross the street utilizing pedestrian cross-walks or traffic islands can all improve the perceived (physical) safety of an environment, and may affect one's propensity for walking or bicycling (Pikora et al. 2003). Personal safety may be affected by fear of hostile people or uncontrolled dogs, and inadequate lighting. For example, physical activity levels are lower in low-income communities and among racial/ethnic minority children due in part to residents feeling unsafe in their communities (Sallis et al. 2006). Convenience may be assured by the presence of sidewalks and paths that are free from obstacles and that form a continuous network linking destinations such as public transportation, shops, recreational facilities, and parks. Aesthetic features, including the size and condition of shade trees, the presence of parks, gardens, and other public features such as benches or artwork also may enhance the potential for active living in an environment (Saelens and Handy 2008). Finally, the availability of nearby destinations such as parks, public amenities, and food outlets may increase the likelihood that people will walk rather than drive.

Understanding the Health Benefits of Physical Activity and Active Transportation

"Few of us will approach these [Olympic athlete] levels of performance in our own physical endeavors. The good news is that we do not have to scale Olympian heights to achieve

significant health benefits. We can improve the quality of our lives through a lifelong practice of moderate amounts [and intensities] of regular physical activity" (David Satcher et al. 1996).

The health benefits of physical activity are well established (Bouchard et al. 2011). Physical activity both prevents and helps treat many established cardiovascular disease risk factors, including elevated blood pressure, insulin resistance and glucose intolerance, elevated triglyceride concentrations, low high-density lipoprotein cholesterol (HDL-C) concentrations, and obesity (Thompson et al. 2003). However, cardiovascular disease is a major cause of morbidity and the leading cause of death among men and women in the United States (Rosamond et al. 2007). Cancer is the second leading cause of death in the United States, responsible for approximately 565,000 deaths each year (about 25% of all deaths); yet, physical activity is also associated with prevention of some cancers, including colon and breast cancer (American Cancer Society 2006; Sternfeld and Lee 2009). In fact, a large body of evidence indicates that physically active men and woman can expect thirty to forty percent reduction in colon cancer risk, and active women can expect twenty to thirty percent reduction in breast cancer risk (Sternfeld and Lee 2009). Moderate or high levels of physical activity also play a role in the prevention of type 2 diabetes, a disease which plagued over 171 million adults in 2000 (and projected to affect 366 million adults in 2030 (Hu et al. 2009; Wild et al. 2004).

Despite the clear case that has been made for the benefits of a physically active lifestyle, as 48 percent of all US adults meet the 2008 Physical Activity Guidelines and less than 3 in 10 high school students get at least 60 minutes of physical activity every day (CDC 2013). The necessity for most people to engage in challenging physical activity has vastly decreased as our countries have become more industrialized over the past century; as a result, our lives have dramatically changed (Bouchard et al. 2011). Many occupations no longer require intensive manual labor and daily housework is not as rigorous. As people become busier, it becomes more difficult to fit physical activity into daily routines.

However, physically active commuting by walking or bicycling can become a promising opportunity for such activity. In fact, health benefits of active transportation are becoming more recognized. One study in Finland revealed that active transportation to work offers substantial potential to be a “health enhancing physical activity” option (Oja et al. 1998). Another Finnish study concluded that moderate or high levels of occupational or leisure-time physical activity among both men and women, and daily walking or cycling to and from work among women were associated with a reduced 10-year risk of chronic heart disease events (Hu et al. 2007).

Another cross-sectional study investigated active transportation and its relationship to risk factors for cardiovascular disease in a large population of civil servants from Benin City, Nigeria. It found that time spent walking or biking to work, compared to other estimates of physical activity, was significantly more highly correlated with most coronary heart disease risk factors (Forrest et al. 2001).

Moreover, a prospective Danish investigation evaluated the relationship between levels of physical activity (during work, leisure time, cycling to work, and sports participation) and all-cause mortality. It concluded that leisure time physical activity was inversely associated with all-cause mortality in both men and women in all age groups. The study also found that 46 percent of 25-year old men and women bicycled to work every day throughout the year and about 70 percent in the summer. Those who did not cycle to work experienced a 39 percent higher mortality rate (Andersen et al. 2000).

A population-based case control study in China concluded that colon cancer risk was significantly reduced among both men and women with high commuting physical activity, particularly among those who had done so for at least 35 years (Hou et al. 2004).

A meta-analysis that examined the association between commuting physical activity and cardiovascular risk demonstrated a robust protective effect of active commuting on cardiovascular outcomes, including mortality, coronary heart disease incidents, stroke, hypertension, and diabetes. The protective effects were more robust among women than men (Hamer et al. 2008).

Matthews et al. (2005) examined long-term exercise participation and high levels of common "non-exercise or lifestyle activities" such as housework or walking for transportation among women. They found a 30-40 percent risk reduction for endometrial cancer in women who have active lifestyles.

In a recent study examining the relationship of neighborhood design to physical activity and BMI, men were found to have a lower BMI and obesity risk if they bicycled to work (Brown et al. 2013). Women who walked to work were associated with lower BMI and lower obesity risk.

A cross-sectional study that included all 50 U.S. states and 47 of the 50 largest cities found that higher rates of walking and cycling to work were associated with (1) a higher percentage of adults who achieved recommended levels of physical activity, (2) a lower percentage of adults with obesity, and (3) a lower percentage of adults with diabetes (Pucher et al. 2010).

Last, U.S. cities with enhanced levels of active transport already experience health benefits. Pucher and colleagues (Pucher et al. 2010) found that cities with the highest rates of commuting by bike or on foot have obesity and diabetes rates 20 and 23 percent lower, respectively, than cities with the lowest rates of active commuting.

These studies confirm the numerous health benefits of incorporating physical activity through active transportation into daily routines.

Status of Bicycling and Walking in the United States and in Europe

The bicycle is not a common mode of transportation for everyday travel in the US, as the 2009 National Household Travel Survey (NHTS) found that only one percent of all one-way trips were made on bicycle. Nationally, about 0.6 percent of workers regularly commuted by bicycle in 2009 (US Census 2009). This number increased from 1990 when it was 0.4 percent.

More trips nationwide are taken on foot, as about 10.5 percent of all trips are walking trips. Unlike bicycling, the percent of commuters who walk to work declined from 1990 to 2009, decreasing from 3.9% to 2.9% (US Census 2009). However, people living in major U.S. cities are 1.7 times more likely to walk or bicycle to work than the national average.

According to the 2009 American Community Survey, bicycle and pedestrian commuters are generally distributed proportionately among ethnic groups; yet, striking differences exist between genders, especially for bicycling trips (US Census 2009). For walking trips in the U.S., 49 percent are by men, while 51 percent are by women. However, among bicycle trips, 76 percent are by men and 24 percent are by women. One explanation for this difference in profile for bicyclists is that women have higher concern for safety, particularly from vehicle travel (Garrard et al., 2008; Handy 1996b). Another explanation is that women need more flexibility than men because they are often more responsible for household chores and childcare; a private vehicle proves flexibility and space for passengers and goods (Clifton and Dill 2005; Spain et al. 1996). Due to women's greater household responsibilities, women often feel more time constrained, and walking or bicycling is not an attractive option (Clifton and Dill 2005; Handy 1996b). When considering age, walking is generally distributed proportionately among age groups; yet, for bicycling, rates decline with age with youth under age sixteen making up 39 percent of total bicycle trips (NHTS 2009).

Unlike Europe, where bicycle trips often are more common than motor vehicle trips, the United States still has room to grow. Nearly 30 percent of Dutch commuters always travel by bicycle, and an additional 40 percent sometimes bike to work (FietsBeraad 2009). In both Germany and Denmark, more than 20 percent of commuters travel by bicycle. High numbers of bicyclists in these European countries are attributed to making cycling attractive, to creating a variety of bicycle-friendly transportation policies, to creating extensive systems of bicycle paths, to promoting mixed-use neighborhoods, and to increased ridership, creating a "safety in numbers" mentality (Block 2013). Thus, many countries in Europe have developed a culture engrossed in bicycling and active living, and the built environment has been designed and developed to foster this culture. Some communities in the United States have embraced bicycling more than others, but many would argue that the United States has not fully adopted a culture of active living.

The Case for Walking and Bicycling

There is a fair amount of evidence for why walking and bicycling can be appealing options for transportation. First, bicycling and walking as modes of transportation require low level of exertion (Frank et al. 2003). For those who are elderly, overweight or obese, or sedentary, these forms of activity may be more appealing as a result. Second, these forms of active transportation impose few barriers on participants, as neither bicycling nor walking requires significant financial resources or facilities. Though a new or used entry-level bicycle necessitates an upfront investment, these bicycles can be relatively inexpensive, allowing a person few material resources the opportunity to partake. Third, walking and bicycling can be fun activities that relieve stress and provide exercise that may contribute to increased worker productivity. Last, for those who lack time for leisure time physical activity, active transportation provides a unique opportunity for meeting physical activity recommendations during the commute.

Understanding Active Transportation in Context Ecological Models

Ecological Models of health behavior are conceptual tools predicated on the notion that human behavior has multiple levels of influences, including individual and environmental (Sallis et al. 2008). The ecological paradigm has evolved over time within biological and behavioral sciences and public health to provide a general framework for understanding the nature of people's transactions with their physical and sociocultural surroundings (i.e. environment) (Stokols 1992). One key feature of ecological models of health behavior is that they incorporate two or more analytic levels (e.g. personal, organization, community), which gives investigators the opportunity to examine both individual and collective manifestations of health problems and impacts of community interventions (Stokols 1996).

Ecological models are being recognized as a productive framework for physical activity promotion because physical activity is done in specific places (Sallis et al. 2006). Directing attention to the personal, environmental, and policy factors that facilitate or hinder physical activity, ecological models can help provide plausible explanations of the root causes of the epidemic of sedentary lifestyles. Figure 1 shows a current ecological model of sedentary behavior for each of the four principal domains of physical activity (household, leisure-time, occupational, and transportation-related physical activity). Distinct policies and environments likely affect each of the physical activity domains with multiple levels of influence in specific settings impacting each physical activity behavior (Owen et al. 2011). The transportation-related activity level is highlighted in red because this is the outcome of interest for this dissertation; however, there are commonalities and overlap across these domains. For instance, when examining the environmental factors, trail systems that link homes and workplaces would be relevant for recreational, transport and work-related physical activity, but not for household activity. The policy environment has a significant opportunity to influence active living by reducing sedentary behavior through a variety of mechanisms including built environment investments, incentive programs, and regulations (Sallis et al. 2006). In the transportation-related activity domain, policies can include zoning codes, regulations (e.g., sidewalk requirements), transportation investments (e.g., separated bicycle paths), traffic demand management, parking regulations, or developer incentives (Figure 1). However, some of these policies may affect other physical activity domains as well.

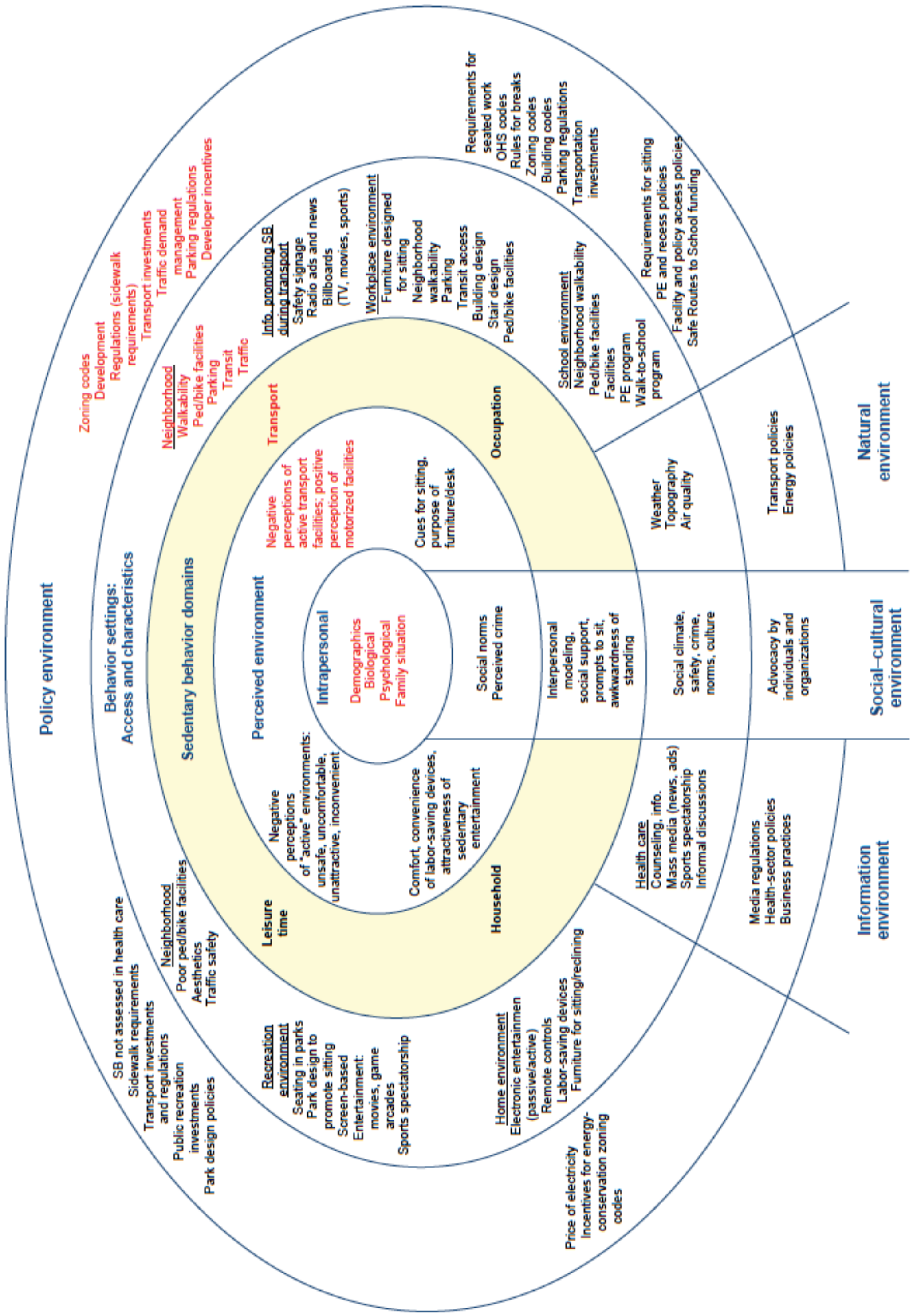


Figure 1 Modified Sedentary Behaviors Ecological Model by Owen et al. 2011

It is important to recognize the intra- and inter- personal environments within this model, which affect the ecological model for physical activity / sedentary behavior. Intrapersonal factors such as family situation and demographics affect all physical activity domains. Social and cultural environmental variables cut across different levels, including social norms and supports and perceptions of safety.

The natural and information environments are not necessarily confined to a specific physical activity behavior setting; yet, they, too, play important roles in the ecological model. Weather, topography, and air quality are all factors in the natural environment that may affect all domains of physical activity, while transportation and energy policies can also affect air quality and climate. Information is omnipresent within all the domains, especially as people battle temptation in media campaigns for calorie-dense food and video games. This ecological model indicates that there exists no "quick fix" for reducing sedentary behaviors because of the large number of variables and complexity of interactions across components. However, no matter how large or daunting the task may be, research remains a critical component of the effort to increase physical activity throughout the population (Sallis et al. 2006). In this dissertation, one goal is to provide better understanding of the neighborhood- and community-level correlates of active transportation to better inform environmental and/or policy level change.

Acknowledging the Role of Diet in Obesity and Health

Eating patterns in the United States are characterized by a high-energy intake and an overconsumption of (saturated) fat, cholesterol, sugar and salt (Hensrund 2004). It is known that obesity occurs when energy intake consistently exceeds energy expenditure (Hill et al. 1999). Because the current trend among Americans is a more sedentary lifestyle, this results in a decrease of daily energy expenditure. Thus, current dietary patterns in conjunction with increased physical inactivity help to explain the current obesity epidemic.

Similar to sedentary behavior as explained above, dietary patterns are influenced by multiple factors that have changed over time. Vast shifts in the foods we eat, food production and processing, food shopping and eating options, agricultural subsidies have all affected dietary patterns. Though the focus of this dissertation is on physical activity through active transportation, it is important to acknowledge the role of diet (in addition to genetic factors) in health.

Understanding Other Co-Benefits of Active Transportation

In the past decade, two societal challenges, obesity and climate change have emerged as public health priorities. Greenhouse gas emissions linked to global climate change have been deemed the most significant threat confronting public health in the 21st Century (Benjamin et al. 2011; Maizlish et al. 2013), and obesity is an increasing global problem that already costs the United States health care system more than $147 billion annually (Finkelstein et al. 2009). Both issues share common sources and impact individuals and communities across the world. In 2009, the United States was the 2nd leading contributor to greenhouse gas emissions worldwide (next to China), responsible for 19% of the total greenhouse gas emissions (Boden and Andres 2012). About one-third of the adults in the United States are estimated to be obese, and roughly two-thirds are overweight or obese (Ogden et al. 2006). The modes we use for traveling have great potential for addressing these two challenges. Reducing burning of fossil fuels for transport by using alternative means will help reduce the rate of climate change and the severity of the impact of climate change, but also have other benefits including health, air quality, and economic benefits.

In 2013, Maizlish and colleagues input the statistics on travel patterns and injuries, physical activity, fine particulate matter, and greenhouse gas emissions in the San Francisco Bay Area, California into a model that calculated the health impacts of walking and bicycling short distances by car or driving low-emission vehicles. They found that by increasing median daily walking and bicycling from 4 to 22 minutes, the burden of cardiovascular disease and diabetes was reduced by 14 % (32,466 DALYs), the traffic injury burden was increased by 39% (5,907 DALYs), and greenhouse gas emissions were reduced by 14%. However, though they found a large net improvement in population health from increasing physical activity associated with active transport, measures to minimize pedestrian and bicyclist injuries are necessary.

Another recent study did not find additional risks from injury, but this was conducted in The Netherlands, where nonmotorized transit is given greater priority. In 2010, Johan de Hartog and colleagues determined that shifting from short car trips to bicycle trips would actually have beneficial effects on all-cause mortality. This is because benefits of increased physical activity greatly outweigh potential mortality risks from both increased pollution inhalation and traffic-related fatalities. In fact, this study estimated that on average, benefits of cycling were about nine times greater than risks from driving in the Netherlands, and sevenfold greater in the United Kingdom.

In addition, studies have shown that the likelihood that a person walking or bicycling will be struck by a motorist varies inversely with the amount of walking or bicycling. In other words, it appears that motorists adjust their driving behavior positively in the presence of people walking and bicycling near or on the roads. One study revealed that the number of conflicts per bicyclist decreased abruptly when more than fifty bicyclists were present per hour (Jacobsen 2003). This study validates efforts to improve city policies in order to increase the number of bicyclists as an effective means of improving the safety of pedestrians and bicyclists.

Another study estimated the potential effect of increased walking and cycling in urban England and Wales and costs for seven chronic diseases associated with physical inactivity (Jarrett et al. 2012). They found that within 20 years of increasing active travel, the reductions in prevalence of disease would lead to savings of roughly 17 billion UK pounds (in 2010 prices), which is equivalent to 26 billion USD (in 2013 prices). Thus, this study highlights the long-term benefits of investing in an active lifestyle.

Summary

This dissertation examines the extent to which the built environment promotes or inhibits active transportation behaviors; and the subsequent benefit of these active transportation behaviors to individuals and their health, as well as the health of the local, regional, and global environments. Chapter 2 addresses the individual and environmental correlates of active transportation. Chapter 3 develops a model to identify and drive future policy decisions focused on the facilitation of utilitarian transport. Chapter 4 examines the many co-benefits of replacing short car trips with bicycle trips. A conceptual model of this dissertation can be found in Figure 2.

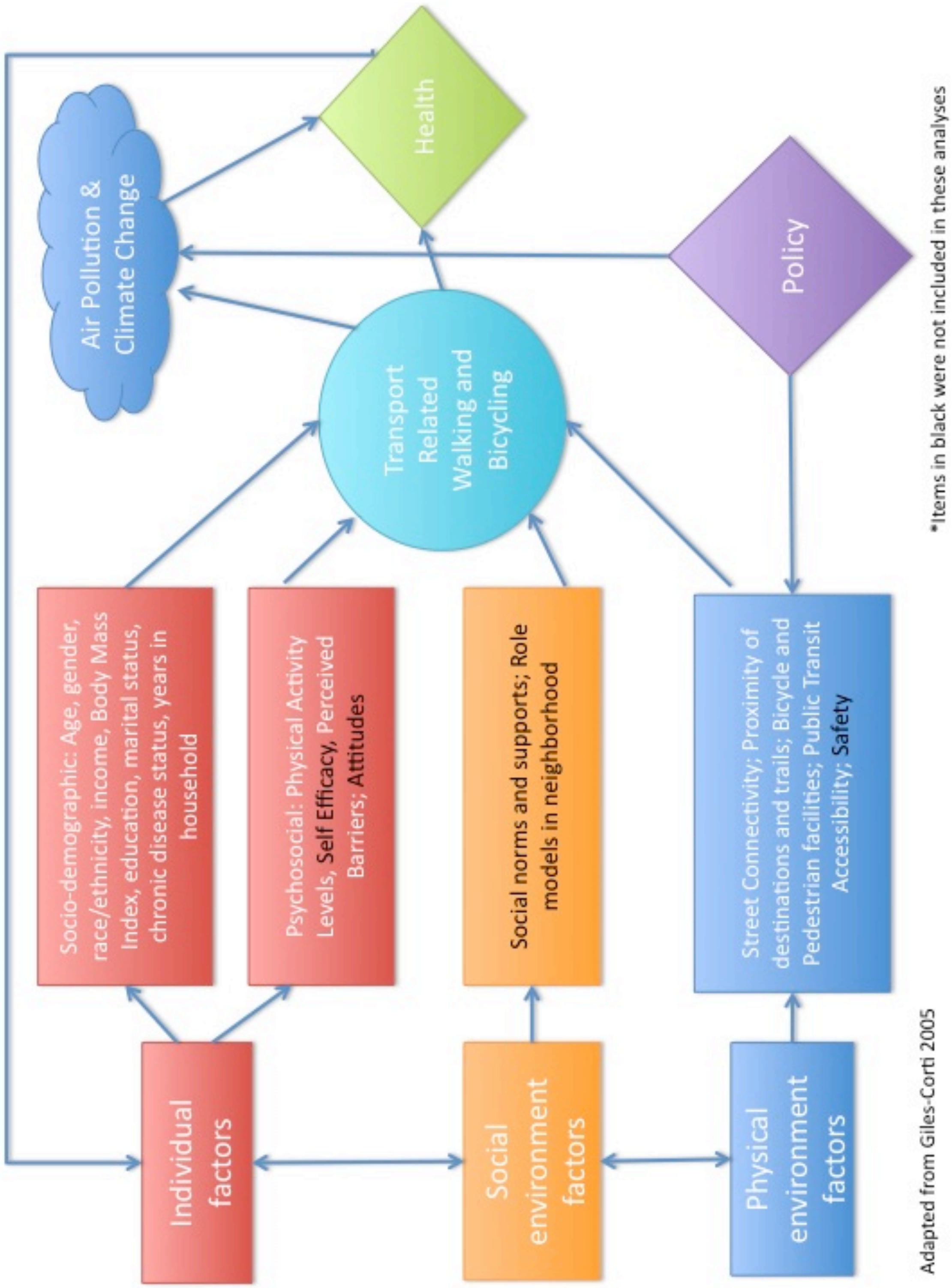
Evidence of the environmental and perceived correlates of walking, especially recreational walking, has been fairly well established. However, research on the perceived and environmental predictors of active transportation is sparser. This dissertation attempts to fill some of the gaps in understanding of the correlates of active transportation behavior.

Furthermore, current active living research tends to focus on “walkability” – the suitability for walking in a community. This dissertation focuses on identifying and measuring the suitability of a place for active transportation, which encompasses walkability, bikeability, and accessibility of public transit, and other features of the built environment such as proximity to destinations and street connectivity. There has yet to be an accessible “gold standard” for measuring active transportation-supportive communities. This dissertation will provide some insight for moving closer to achieving that gold standard.

Common sense tells us that taking car trips off the road will reduce air-pollution induced health problems and decrease global climate change causing greenhouse gas emissions.

It logically follows that replacing these car trips with bicycle trips will increase physical fitness and prevent ailments of a sedentary lifestyle. As a result, there will be fewer medical bills for chronic diseases associated with air pollution and physical activity. However, until these benefits are quantified, there is no impetus to promote active transportation in communities. This dissertation seeks to provide a basis for catalyzing promotion and support of active transportation for all people in every type of community.

Figure 2. Conceptual Model for this Dissertation



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Chapter 2

Comparison of Perceived and Objective Determinants of Active Transportation Behaviors in Wisconsin

Abstract:

Background: On average in the United States, approximately 3.5 percent of commuting trips are taken by foot or bicycle, 5 percent by public transit, and the remaining 91.5 percent by motor vehicle. Lack of regular physical activity has been identified as one of the most significant public health issues in the United States, and the global significance of physical inactivity is increasing as developing countries adopt more Western modes of transportation. Recent evidence suggests that the physical design of the places where people live and work affects overall travel choices and the extent to which commuters utilize active transportation methods. However, studies to date offer an unclear picture of what specific neighborhood elements facilitate these modes of transport.

Aims: To analyze the association between objective measures of the built environment and active transportation behavior. Concurrently, to examine the association between people's perceptions of their built environment and their subsequent propensity to use active transportation.

Methods: Analysis of the interview-based and self-report data from the Survey of the Health of Wisconsin (SHOW) and the observational Wisconsin Assessment of the Social and Built Environment (WASABE), an ancillary study of the SHOW to assess attributes of the physical environment surrounding households of 1,029 adult residents living in urban, suburban, and rural communities. Active transportation behaviors were linked to environmental audit data and using geographic information systems (GIS) data.

Results: Both perceived and objective observations of many destinations within walking distance from home were positively associated with active transportation. Objectively measured bicycle friendliness (presence of a bike lane or road width supportive of bicycles), presence of trails, and sidewalk availability were also associated with active transportation.

Conclusions: Active transportation behaviors are likely to be associated with individuals' perceptions of their built environment, but primarily with the presence of proximal destinations, trails, and streets supportive of bicycling and walking.

Background/ Introduction

In the United States, approximately 3.5 percent of commuting trips are taken by foot or bicycle, 5 percent by public transit, and the remaining 91.5 percent by private motor vehicles (NHTS 2009). Lack of regular physical activity has been identified as one of the most significant public health issues in the United States, and the global significance of physical inactivity is increasing as developing countries adopt more Western modes of transportation. Physical inactivity is associated with increased risk of several adverse health outcomes including heart disease, type 2 diabetes, colon cancer, breast cancer, and mortality (Colditz et al. 1997; Kelley and Goodpaster 2001; Kohl 2001; Verloop et al. 2000). Active transportation, or commuting by bicycling or walking, might provide one opportunity to meet physical activity recommendations and minimize adverse sedentary behaviors.

There is significant evidence of the protective effects of active commuting against mortality, cardiovascular disease, and endometrial and colon cancers (Anderson et al. 2000; Hamer et al. 2008; Hou et al. 2004; Matthews et al. 2005; Zheng et al. 2009). Rates of physical activity have been associated with various attributes of the built environment (Ewing et al. 2003; Frank et al. 2005; Saelens et al. 2003; Sallis et al. 2005). Furthermore, the physical design of the places where people live and work may also affect overall travel choices and how much commuters utilize active transportation methods (Ewing and Cervero 2001; Frank 2000; Sallis et al. 2004). Other research has shown that perception may play an important role in the effects of the environment on human behavior, specifically physical activity (Blacksher and Lovasi 2012; Duncan et al. 2005; Ferdinand et al. 2012; Giles-Corti and Donovan 2002; Humpel et al. 2002; McCormack et al. 2004; Sallis et al. 2009). However, few if any studies have specifically examined the relationship between neighborhood perceptions and active transport. Current evidence presents an unclear picture of what identifiable neighborhood elements (or perceptions thereof) facilitate or hinder active modes of transport (Brownson et al. 2001; Ferdinand et al. 2012; Grasser et al. 2012). Using survey questionnaires and environmental audit data in Wisconsin, this study seeks to examine both perceived and observed neighborhood characteristics associated with active transportation in order to determine which is a stronger predictor of active transportation in a geographically diverse population.

Methods

Study Overview and design

Two primary data sources were utilized: (1) in-person interviews, self-administered questionnaires, computer-assisted surveys, physical measurements, and laboratory tests of neighborhood residents as part of the Survey of the Health of Wisconsin (SHOW) survey; and (2) a neighborhood "built environment" audit to assess the objective physical and social environments as part of the Wisconsin Assessment of the Social and Built Environment (WASABE) survey.

Data for this cross-sectional study were collected between 2009 and 2011 throughout the state of Wisconsin as part of the SHOW program. SHOW is a statewide study modeled after the National Health and Nutrition Examination Survey (NHANES) that annually gathers health-related data from a representative sample of Wisconsin residents. Each adult participant completes a questionnaire regarding physical and mental health history, demographics, and behavior, including diet and occupation, household, environment, and healthcare access and utilization. SHOW participants also receive a physical examination, including blood pressure, blood draw, urine collection, and height and weight measurements (Nieto et al. 2010).

For this study, SHOW participants provided information on their demographic and health characteristics via personal interviews, while perceptions of their community environment were recorded via self-administered questionnaires. Active transportation activity was measured using a modified International Physical Activity Questionnaire (IPAQ) (Hagstromer et al. 2006).

Ancillary to SHOW, the Wisconsin Assessment of the Social and Built Environment (WASABE) study used a direct observation instrument developed and validated by SHOW investigators to assess neighborhood indicators of the physical and social environment surrounding participating households that may encourage or discourage physical activity (Engelman et al. 2009). The WASABE instrument covers neighborhood characteristics, the transportation environment, land use and types of destinations, the social environment, and potential for street connectivity. More information regarding the reliability, construct validity, and methods of the WASABE tool are in Malecki et al. 2013.

Using the WASABE instrument, neighborhood attributes were assessed within a 400-meter street-network buffer surrounding SHOW participants' home addresses (See sample map in Figure 3). Distances from homes are often measured using the street network, as it reflects actual routes for walkers and bicyclists (Handy 1996). Studies have commonly used 400 meters as a perceived walkable distance for adults (about 5-10 minutes of walking) (Boehmer et al. 2007; Hoehner et al. 2005; Pikora et al. 2003; Pikora et al. 2006; Smith et al 2010). Geographic information systems software ArcMap 10 was used to link the survey with the environmental audit data.

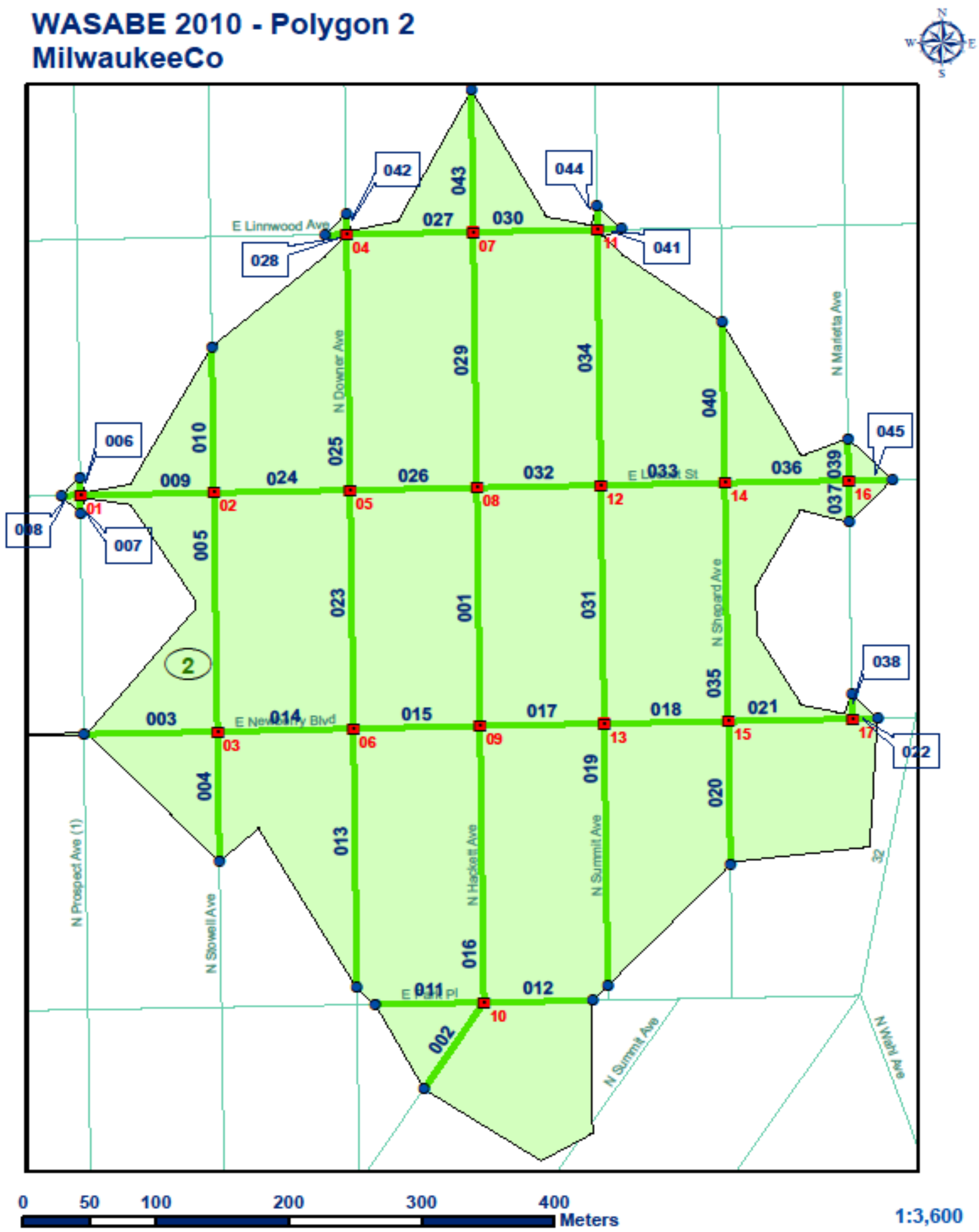


Figure 3 Sample WASABE Household Map

Outcome / Dependent Variable - Active Transportation Measures

Questions from SHOW gathered via personal interview and based on the International Physical Activity Questionnaire (IPAQ), were used to determine participation in active transportation. Participants provided information about whether or not they engaged in such activity (walking or bicycling as part of getting to and from work, or school, or to do errands) over the past 30 days. Respondents specified the total time (in minutes or hours) and number of days over the past month that they spent bicycling and walking. A binary variable for active transportation was created, defined as whether or not active transport was conducted, and used as the outcome variable for the logistic regression models.

Primary Predictors

Objective Environmental Measures

Objective measures of neighborhood physical environments were collected using the WASABE instrument and mapped using GIS software. Observational data were collected individually by trained research assistants at the segment level, that is, each street section between intersections, and then aggregated to the 400 meter buffer level for analysis. The data can be classified into four domains: recreational opportunities, land use, transportation, and social capital. Physical activity supports in the community were assessed by counting the number of recreational facilities within the neighborhood. These included indoor fitness facilities, fields for softball, soccer, etc., tennis courts, running tracks, playgrounds, golf courses, and pools. We assessed whether at least one was present within the 400-meter neighborhood. Land use was determined by counting the total number of nonresidential destinations within the neighborhood, including grocery stores, gas stations, pharmacies, restaurants, banks, and coffee shops — in short, all places that would provide regular daily commercial activity and that were likely to generate walking or cycling trips (Vargo et al. 2012). The transportation environment was measured according to whether neighborhoods had segments containing mostly sidewalks and/or bike lanes or roads wide enough to support coexisting bicycles and cars. Social capital and aesthetics were measured by the percentage of various public features, good and bad, within the neighborhood environment; for example, graffiti vs. attractive outdoor art, the presence of shade trees, the condition of buildings, and amenities such as benches, trash cans, and bicycle racks. The percentage of graffiti, however, was the only social capital and aesthetics variable kept in the model, due to goodness of fit. Details regarding the development of the audit instrument can be found in Malecki et al. (2013).

Perceived Environmental Measures

The SHOW survey uses a self-administered questionnaire to obtain information about perceived neighborhood attributes, including questions about community environments. The same four domains as the objective measures can also categorize perceived features of the built environment (see Table 1 for specific questions). The first of two requests about recreational opportunities seeks a subjective evaluation of the options by asking respondents to rate the community as a place to be physically active. The second question concerns the proximity of trails to the participant's home. The land-use question examines perspective on the number and diversity of destinations within close proximity to the participant's home. The transportation question focuses on the degree of safety from traffic for walking or bicycling in the community. Lastly, to examine the perceived visual attractiveness and upkeep of the community, the question on social capital/aesthetics asks participants to rate his or her degree of agreement with the concept that the community is "well-maintained." Due to the distribution of responses, all data except those on proximity of trails were combined into three categories for analysis to ensure adequate numbers for modeling (e.g., very safe, somewhat safe, and unsafe).

Confounding Variables

Participants were asked about their age, gender, marital status, duration living at their current address, highest education attainment, household income, race, and history of chronic disease. To determine chronic disease histories, participants were asked if a physician had ever told them that they had hypertension, congestive heart failure, diabetes, high cholesterol or asthma. Participants were deemed physically active if they achieved 600 MET/min per week of physically activity, not including active transportation. Measurements for body mass index (height and weight) were obtained by clinical exam. A total of 1,029 adults residing in Wisconsin were included in this study, of whom 326 utilized active transportation. "Urbanicity classification" was determined based on Rural Urban Commuting Area codes (RUCA codes). RUCA codes are based on the Census Bureau's definitions of Urbanized Areas and Urban Clusters, which are based on complex criteria including population density and population work commuting patterns. RUCA taxonomy is based on the size of cities and towns and their functional relationships as measured by work commuting flows (Hart et al. 2005).

Table 1: SHOW Neighborhood Perception Questions and Related Objective Measures

Domain	**SHOW Perception Question**	**WASABE Objective Measure (within 400 m street network buffer)**
Recreation	*Rate your community as a place to be physically active (very pleasant, somewhat pleasant, not very pleasant, or not at all pleasant.*	Presence of recreational facilities including indoor fitness facilities; softball, soccer, or football fields; tennis courts, running tracks playgrounds golf courses; pools
	How many minutes it would take to walk from home to the nearest trail: 10 minutes or less, 11 to 20 minutes, 21 to 30 minutes, more than 30 minutes or don't know any trails within walking distance.	Presence of walking or bicycling trails
Land Use	*There are many destinations within easy walking distance of my home (strongly agree, agree, disagree, or strongly disagree).*	Count of total nonresidential destinations including grocery stores, gas stations, pharmacies, restaurants, banks, and coffee shops
Transportation	*How safe from traffic is the community for walking or riding a bike (very safe, somewhat safe, not very safe, and not at all safe).*	% of streets in neighborhood having mostly sidewalks; % of streets in neighborhood wide enough to support coexisting bicycles and cars
Social Capital and Aesthetics	*My community is well maintained (strongly agree, agree, disagree, or strongly disagree).*	% of graffiti in neighborhood

Statistical Analysis

All statistical analyses were conducted using SAS, version 9.3 (SAS Institute Inc., Cary, NC). Descriptive characteristics of the study population can be found in Table 2. We performed chi-squared tests to assess the relationship between the demographic variables and the outcome variable, active transportation. To assess the relationship of demographic measures, objective measures, and perceptions with one another, we calculated Spearman correlation coefficients between all pairs of variables. These coefficients were also used to assess collinearity and to enable further regression analyses with active transportation as the outcome. To avoid issues of collinearity among predictors, those with correlation estimates larger than $p=0.5$ were excluded from the models.

We employed multivariate logistic regression to test the impacts of certain objective and perceived built environment predictors on active transportation. The regression models were adjusted for demographic characteristics (age, gender, education, household income, body mass index (BMI), chronic disease status, urbanicity classification, race/ethnicity, physical activity, and marital status). Age (21-74) and BMI (17-67) were included in the model as continuous variables. Gender, marital status (married or living with partner or unmarried), race/ethnicity (white or Hispanic + non-white), physically active (MET minutes per week score of at least 600) and chronic disease status were considered binary variables. Education and household income were categorical variables as determined by SHOW experts (Nieto et al. 2010). Urbanicity was also considered as a categorical variable (urban, suburban, and rural).

Three phases of modeling produced a parsimonious multivariate model for the dependent variable, active transportation: (1) demographic variables only, (2) objective predictors only, and (3) a combination of the first two plus perceived predictors. Using a manual backward elimination procedure and observance of model fit, environmental and perceived predictors were removed if they were not statistically significant ($p<0.30$) and if the Hosmer and Lemeshow Goodness-of-Fit test was less than 0.1. Effect modification by urbanicity classification was assessed by additional terms incorporated in the total sample model (e.g., urbanicity X presence of recreational facilities) with statistical significance determined at $p=0.10$. All perceived predictors were tested for effect modification by urbanicity classification and years of residency in the household. Lastly, each objective indicator was paired with the corresponding perceived indicator and tested to see if the perceived indicator mediated the relationship between the objective indicator and active transportation.

Results

Sample

The final sample included 1,029 participants from 689 households. The distribution of gender, race/ethnicity, age, educational attainment, chronic diseases status, and income is provided for the total sample (Table 2). There were 458 males and 571 females considered in the study, with each gender having 163 people actively transporting, for a total of 326 (roughly 1/3 of the study population). For distribution of people conducting active transportation across Wisconsin in urban, suburban, and rural areas, see map in Figure 4. The majority of participants in this study were of non-Hispanic white ethnicity, with about 88 percent of those participating in active transport being white.

Six objective and five perceived indicators from each of the four domains — land use, recreational opportunities, transportation, and aesthetics — remained in the final multivariate model. All objective predictors were tested for effect modification by urbanicity classification, and none were significant. There was no significant effect modification found between the perceived predictors and urbanicity classification or years of residency in the. Lastly, there was no evidence of mediation in the relationship between the objective and perceived indicators and active transportation.

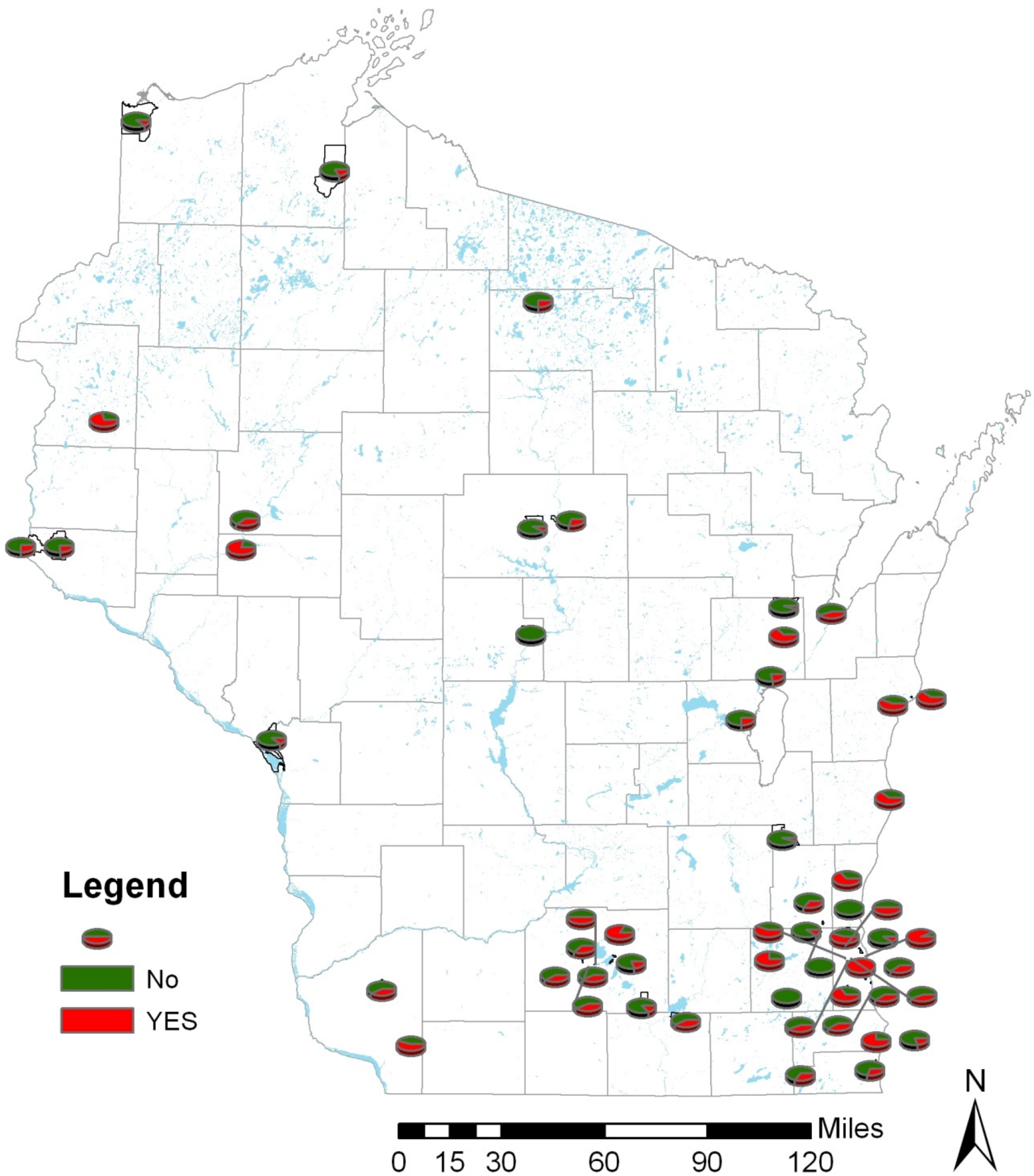
Table 2 Descriptive Characteristics of Study Population, Including Active Transportation (AT) Levels

Study Population	~1029		~326		
Sample Characteristics	**N**	**% of Sample**	**N = # using AT**	**% using AT**	**AT Chi-Squared**
Gender					0.0188
Male	458	44.5%	163	35.6%	
Female	571	55.5%	163	28.5%	
Age					<0.0001
21-30	184	17.9%	91	49.5%	
31-40	171	16.6%	47	27.5%	
41-50	222	21.6%	62	27.9%	
51-60	242	23.5%	65	26.9%	
61-75	209	20.3%	61	29.2%	
Race/Ethnicity					0.0026
White	939	91.5%	285	30.4%	
Non-White	87	8.5%	39	44.8%	
Marital Status					<0.0001
Married, lives with partner	673	65.6%	175	26.0%	
Not Married	353	34.4%	150	42.5%	
Education					0.1401
High school graduate or less	23	2.3%	7	30.4%	
Some college	612	62.3%	181	29.6%	
College or beyond	348	35.4%	125	35.9%	
Family Income					<0.0001
Above 100% Federal Poverty Level	877	87.6%	64	7.3%	
Below 100% Federal Poverty Level	254	12.4%	124	48.8%	
Residency in Household					<0.0001
3 or more years	737	73.0%	207	28.1%	
Less than 3 years	273	27.0%	114	41.8%	
Body Mass Index					0.002
<25	380	36.9%	129	33.9%	
25< BMI <35	307	29.8%	112	36.5%	
>35	342	33.2%	85	24.9%	
Chronic Disease Status					0.5273
Without	403	43.7%	125	31.0%	
With	519	56.3%	171	32.9%	
Physically Active					<0.0001
Yes	642	64.5%	261	40.7%	
No	354	35.5%	58	16.4%	
Urbanicity Classification					<0.001
Urban	127	12.3%	63	49.6%	
Suburban	385	37.4%	143	37.1%	
Rural	517	50.2%	120	23.2%	

Active Transportation in SHOW Participants

In the final adjusted multivariate model, which included both objective and perceived predictors, certain demographic characteristics were significantly associated with active transport among participants. Physically active people, those with a previous chronic disease diagnosis, and those with more education had a greater likelihood of participating in active transport aOR=2.859 (95% CI: 1.77, 4.61; $p<0.0001$), aOR=1.787 (95% CI: 1.20, 2.67; $p=0.0046$), and aOR=1.262 (95% CI: 1.10, 1.45; $p=0.0013$) respectively (See Table 3). In addition, those having a body mass index (BMI) of over thirty, who are considered obese, had greater odds of not actively transporting (aOR=0.678 95% CI: 0.43, 1.08; $p=0.0365$). However, urbanicity classification, age, gender, race/ethnicity, income, number of years residing in the current household, and marital status were not significantly associated with active transportation in the final model.

Figure 4 Percentage of Sample Actively Transporting in Wisconsin



Primary Predictors

Land Use

In both adjusted models, the number of destinations in a 400-meter neighborhood was significantly associated with active transportation. In the adjusted model with only objective environmental variables, each additional destination increased the odds of active transportation by 4.7 percent (aOR=1.047, 95% CI: 1.02, 1.08, p=0.0036). Adding perceived indicators to the model negligibly increased the likelihood of active transportation to 6.4% (aOR=1.064, 95%CI: 1.03-1.01, p=0.0006).

Those conducting active transportation were more likely to agree that many destinations exist within close proximity in their community (aOR=1.362, 95% CI: 1.03, 1.81, p=0.0317). This perception variable of presence of many destinations was the only significant perception variable in the complete model.

Transportation

Our findings suggest that having a higher percentage of bicycle-friendly roads is associated with more people using active transport. This is true in both adjusted models, aOR=1.008 (95% CI: 1.00, 1.01, p=0.0002) without perception variables, and aOR=1.007, 95% CI: 1.00, 1.01, p=0.0095) for the complete model that includes the perception variables. An even stronger predictor, the greater presence of sidewalks, indicates a significant likelihood of active transportation (aOR=2.426 95% CI: 1.41, 4.18) in the model with only objective variables and (aOR=1.807 95% CI: 0.99, 3.30, p=0.0539) when both objective and perceived variables are used).

There was no significant association between active transport and perceived safety from traffic for bicycling and walking. Similarly, we did not find a significant association between perceived presence of trails within walkable distance and active transportation. While not statistically significant, as people perceived the level of traffic safety to be greater for walking and bicycling, so did their level of active transportation (aOR=1.091, 95% CI: 0.80, 1.49, p=0.5796). Perceived proximity of trails in these neighborhoods was also not significantly associated with active transportation (aOR=1.055, 95% CI: 0.799-1.198, p=0.5569).

Physical Activity/Recreational Opportunities

Presence of any type of recreational opportunity within the neighborhood was significantly associated with decreased odds of people actively transporting in the complete model with both objective and perception variables (aOR=0.582, 95% CI: 0.38, 0.89; p=0.0132). Presence of trails was significantly associated with active transportation in the model with only objective variables (aOR=1.511, 95% CI: 1.01-2.25; p=0.0423).

We found no significant associations between perceived rating of support for physical activity in the community and active transportation. Though insignificant, as the rating of physical activity supportiveness improved, so did the likelihood of active transportation (aOR=1.362, 95% CI: 0.97, 1.91; p=0.0755). Similarly, there was no association between perception of proximity to trails and active transportation; however, there was a positive, yet insignificant relationship (aOR=1.055 95%CI: 0.88, 1.26; p=0.5569).

Table 3 Logistic Regression Results: Environmental and Perceived Predictors and their Association with Active Transportation Behavior in Wisconsin

	Model 1: Only Demographics and Objective Variables				Model 2: Demographics, Objective, & Perceived Variables			
Variable	**aOR**	**5% CI**	**95% CI**	**p-value**	**aOR**	**5% CI**	**95% CI**	**p-value**
Gender				0.3610				0.3742
Female	1.000				1.000			
Male	1.164	0.84	1.61		1.176	0.82	1.68	
Age	0.996	0.98	1.01	0.6173	1.000	0.99	1.02	0.9541
Race/Ethnicity				0.2145				0.0936
Non-Hispanic White	1.000				1.000			
Non-White	1.470	0.80	2.70		1.825	0.90	3.69	
Education	**1.270****	1.12	1.44	0.0002	**1.262****	1.10	1.45	0.0013
Body Mass Index				0.1351				
Normal Weight	1.000							
Overweight	1.151	0.78	1.71	0.1154	1.087	0.70	1.68	0.1474
Obese	0.750	0.50	1.13	0.0568	**0.678****	0.43	1.08	0.0365
Marital Status				0.0946				0.0654
Married	1.000				1.000			
Not Married	1.412	0.94	2.12		1.527	0.97	2.40	
Chronic Disease Status				0.0363				0.0046
No Chronic Disease Diagnosis	1.000				1.000			
Chronic Disease Diagnosis	**1.505****	1.05	2.16		**1.787****	1.20	2.67	
Physical Activity (Not AT)				<0.0001				<0.0001
Not Physically Active	1.000				1.000			
Physically Active	**2.724****	1.78	4.17		**2.859****	1.77	4.61	
Income	0.344	0.10	1.20	0.1879	0.525	0.13	2.06	0.3876
RUCA (Urbanicity)	1.024	0.97	1.08	0.4203	1.024	0.96	1.09	0.4466
Years in House	1.003	0.99	1.02	0.7025	0.995	0.98	1.01	0.6108
% Bicycle Friendly Streets	**1.008****	1.00	1.01	0.0002	**1.007****	1.00	1.01	0.0095
% Sidewalks	**2.426****	1.41	4.18	0.0014	**1.807****	0.99	3.30	0.0539
Total Destinations	**1.047****	1.02	1.08	0.0036	**1.064****	1.03	1.10	0.0006
Presence of Graffiti	0.995	0.95	1.04	0.8124	1.006	0.96	1.06	0.8080
Presence of Trails	**1.511****	1.01	2.25	0.0423	1.501	0.95	2.37	0.0800
Presence of Rec. Facilities	0.713	0.49	1.05	0.0856	**0.582****	0.38	0.89	0.0132
****=p<0.05**	**Perception of Many Destinations**				**1.362****	1.03	1.81	0.0317
	Physical Activity Rating				1.362	0.97	1.91	0.0755
	Safety from Traffic				1.091	0.80	1.49	0.5796
	Perception of Proximity to Trails				1.055	0.88	1.26	0.5569
	Perception of Well-Maintained Community				0.780	0.55	1.11	0.1646

Social Capital and Aesthetics

The only neighborhood aesthetics feature left in the final multivariate model was percentage of segments in the neighborhood having graffiti. Presence of graffiti, though not significant, had little effect on active transportation in both final models (aOR=0.995, 95% CI: 0.95, 1.04; p=0.8124 and aOR=1.006, 95% CI 0.96, 1.06; p=0.8080).

The extent to which people perceive their community to be well-maintained had an inverse relationship to active transportation; yet, it was not statistically significant. Those perceiving their community to be well-maintained had less likelihood of conducting active transportation (aOR=0.780, 95% CI: 0.55, 1.11; p=0.1646).

Urban vs. Non-Urban Predictors

Since this study was conducted across the state of Wisconsin with participants living in very geographically diverse areas, we stratified our analysis by those living in urban areas and those living in non-urban areas. People living in urban areas had greater odds of actively transporting with more nonresidential destinations present in their neighborhood (aOR=1.049, 95% CI: 1.01-1.10; p=0.0268). Moreover, those living in urban areas who rated their community to be supportive of physical activity also had greater odds of active transportation (aOR=1.783, 95% CI: 1.13, 2.83; p=0.0138).

Similarly in non-urban areas, as numbers of destinations increased in neighborhoods, so did the likelihood of active transportation (aOR=1.069 95% CI: 1.00, 1.14; p=0.0540) (See Table 4). However, there were some predictors of active transportation within the non-urban areas that did not exist in urban areas. For instance, people who were considered overweight (having a BMI between 25 and 30), were significantly and strongly associated with active transportation (aOR=2.117, 95% CI: 1.04, 4.33; p=0.0075). The presence of bicycle supportive streets was positively associated with active transportation in non-urban areas; though, this association was not a very strong one (aOR=1.01, 95% CI: 1.00, 1.02; p=0.0407). Last those who perceived many destinations within close proximity to the home had increased likelihood to active transport (aOR=1.539, 95% CI: 0.98 – 2.41; p=0.0605).

Table 4 Stratifying by Participants Living in Urban and Non-Urban Areas

	Model 3: Full Model Stratifying for Urban Only Participants				Model 4: Full Model Stratifying for Non-Urban Participants			
Parameter	**aOR**	**5% CI**	**95% CI**	**p-value**	**aOR**	**5% CI**	**95% CI**	**p-value**
Years in Home	1.003	0.98	1.03	0.8171	0.985	0.96	1.01	0.2685
Gender				0.2735				0.8396
Female	1				1			
Male	1.302	0.81	2.09		0.944	0.54	1.66	
Age	0.995	0.97	1.02	0.6776	1.004	0.98	1.03	0.7618
Race/Ethnicity								0.9899
Non-Hispanic White	1			0.0803	1			
Non-White	1.954	0.92	4.14		na	na	na	
Education	1.19	0.99	1.43	0.0648	1.501**	1.20	1.88	0.0004
BMI				0.4363				
Normal	1				1			
Obese	0.667	0.36	1.24	0.2775	0.878	0.43	1.81	0.1023
Overweight	0.807	0.45	1.44	0.9634	2.117**	1.04	4.33	0.0075
Marital Status				0.5350				0.3873
Married	1				1			
Non-Married	1.799	0.99	3.27		1.375	0.67	2.83	
Chronic Disease Status				0.2033				0.0043
No Chronic Disease	1				1			
Chronic Disease Diagnosis	1.411**	0.83	2.40		2.504**	1.33	4.70	
Physical Activity				0.0024				0.0025
No	1				1			
Yes	2.517**	1.39	4.56		3.512**	1.56	7.93	
% Bicycle Supportive Streets	1.005	1.00	1.01	0.1723	1.01**	1.00	1.02	0.0407
% Sidewalks	1.523	0.77	3.01	0.2268	1.629	0.48	5.51	0.4328
Total Destinations	1.049**	1.01	1.10	0.0268	1.069**	1.00	1.14	0.0540
Graffiti	1.045	0.92	1.18	0.4886	0.978	0.92	1.04	0.5080
Prence of Trails	1.3	0.72	2.34	0.3832	1.445	0.65	3.19	0.3629
Presence of Rec Facilities	0.763	0.45	1.30	0.3171	0.368	0.18	0.77	0.0084
Perception of Many Destinations	1.355	0.93	1.98	0.1159	1.539**	0.98	2.41	0.0605
Physical Activity Community Rating	1.783**	1.13	2.83	0.0138	0.888	0.53	1.49	0.6513
Safety from Traffic	0.962	0.65	1.43	0.8458	1.347	0.83	2.18	0.2252
Perception of Proximity to Trails	0.98	0.76	1.26	0.8742	1.187	0.92	1.54	0.1936
Perception of Community Well-Maintained	0.748	0.48	1.17	0.1986	0.654	0.37	1.15	0.1371

Discussion

We sought to examine which perceived and objective measures could explain active transportation behavior in adults living throughout the state of Wisconsin in urban, suburban, and rural neighborhoods. As a first research question, we examined the moderating effects of urbanicity classification on both objective and perceived predictors of active transportation. We hypothesized that there was potential for interaction by level of urbanization because exposure to the physical environment can vary quite drastically depending on whether neighborhoods are urban, suburban, or rural. We found no significant interaction. Our second research question was to test the interaction of number of years living in the household on perceptions of the physical environment; again, no significant interaction was established. Third, we sought to determine whether perceptions of the physical environment mediated the pathway between objective measures of the environment and active transportation; once again, there was no significant evidence of mediation. In the absence of effect modification or mediation, we were able to explain the following environmental and perceived predictors of active transportation behavior in Wisconsin adults.

Demographics

In this sample of Wisconsin adults, those conducting active transport were more physically active, had a history of one or more chronic diseases, and were more highly educated. Those who have a propensity toward physical activity might also seek the benefits of that activity elsewhere, and in this case, through active transportation. Those previously diagnosed with a chronic disease were more likely to conduct active transport, perhaps indicating that experience with disease provides impetus for improving health by increasing the levels of physical activity, with active transportation being a practical option to do so.

Lastly, as educational experience increased, so did the likelihood of active transportation. This may signify that those with more education have greater awareness of the health benefits of physical activity, in this case through active transportation. Other research has seen this relationship between higher education and awareness of physical activity. For instance, Diboudeahduij et al., 2003, found that higher educated study participants reported more ease to walk to a public transportation stop, more possibilities to be active in the work environment, and more convenient physical activity facilities compared to participants with lower education. Another study observed that higher education has a negative and highly significant effect on the probability of car use – which could be explained by a more pronounced environmental consciousness or a person more acquainted with the benefits of exercise (Vance et al. 2005).

Land Use

We found increased proximity to non-residential destinations to be associated with active transportation, for both objective measures (in both final models) and perceived land-use measures. In fact, perceived presence of many destinations within one's community was our strongest perception predictor of active transportation. This finding is consistent with Hoehner et al. (2005) and other studies in the urban planning literature (Frank et al. 2000; Handy and Clifton 2001; Saelens and Handy 2008). Mixing land-uses and thereby decreasing the distances between destinations is believed to be an important strategy for increasing active transportation (Frank et al. 2003). This suggests that incorporation of non-residential destinations within communities, rather than keeping land uses separate, can provide an opportunity for active transport that may be beneficial to health.

When considering destinations surrounding SHOW participant's households, the perception of many destinations was a slightly stronger predictor of active transportation than their actual presence. However, both were robust correlates of active transportation in our multivariate model, indicating that the built environment features that predict active transportation are independent of how people perceive their built environment.

Many other studies, which confirm our findings, tended to examine only walking for utilitarian purposes or walking for recreation, rather than considering walking or bicycling for transportation or all-inclusive active transportation. For instance, Pikora et al. (2006) found the presence of destinations to be positively associated and significantly related to walking for transportation; however, they did not find a significant relationship between walking for recreation and destination factors. Lee and Moudon (2006) reported a strong association between destinations and walking both for transportation and for recreation. We are adding to the limited pool of research on this topic, since our study is not limited to walking only for transport; however, we include both walking and bicycling as means of transportation. King et al. 2003 observed a positive trend between the total number of destinations within walking distance from the home and recreational walking. Last, Strath and colleagues identified non-residential destinations to be a significant predictor of moderate to vigorous physical activity among older adults (Strath et al. 2012).

Transportation

Bicycle-Friendly Streets

Those living in neighborhoods with streets that are supportive of bicycling, that is, that have either bicycle lanes or greater width, were more apt to actively transport. This is in accordance with other studies that documented an association between presence of supportive bicycle facilities and physical activity levels (Dill and Carr 2003; Titzke 2008). Though this association between active transportation and the presence of bicycling infrastructure is not highly robust, we still found a statistically significant association. This finding corroborates planning and policies that transform streets to support bicycling.

We did not find a significant correlation between increased presence of bicycle-friendly streets and the subsequent perception of safety from traffic for walking and bicycling. However, the SHOW questionnaire did not query participants directly about the quality of the bicycling environment within their community, and this could have elicited a greater perception response. Also, there may be other psychological, cultural, and behavior factors involved that explain this lack of agreement between the objective and perceived indicators of active transportation behavior. As researchers have noted, people perceive their environments based on various types of lifestyle behaviors, personal beliefs and experiences, and cultural values, all of which may affect perception of safety from traffic (Kirtland et al. 2003).

Sidewalk Availability

Greater presence of sidewalks within neighborhoods increased the likelihood of active transportation behavior among study participants. Sidewalk presence was the greatest objective predictor of active transportation in this study in both of our fully adjusted models. This finding is consistent across other studies, as presence of sidewalks has been invariably found to be correlated with walking (DeBourdeaudhuij et al. 2003; Saelens and Handy 2008). Other studies have found presence of sidewalks to be associated with physical activity (Brownson et al. 2001). In our study, people were almost twice as likely to actively transport as the percentage of sidewalk availability increased, and this likelihood did not change significantly when the perception variables were added to the model. This suggests that the objective environmental variable of sidewalk presence is not attenuated by perceived built environmental features. This offers a significant public health opportunity for communities that improve sidewalk infrastructure within neighborhoods. One method of supporting improved sidewalk infrastructure is to implement municipal zoning code requirements.

Physical Activity/Recreational Support

The likelihood that there is a recreational facility in the neighborhood is lower among those who actively transport. Perhaps those who do so do not find it necessary to obtain their exercise from recreational facilities, and get their exercise through other means, such as walking and bicycling to their destinations. It is also important to recognize that our definition of neighborhood is inherently limiting, since having a geographic boundary of 400 meters may not encapsulate all nearby recreational opportunities for study participants.

Despite the preceding counter-intuitive finding, our study shows that people who rate their community high as a place to be physically active are more likely to actively transport.

This supports the previous hypothesis that other recreational facilities exist beyond the 400 meter buffer.

Most studies assess the association between recreational walking for physical activity with the presence of recreational facilities rather than considering the association between utilitarian physical activity and the presence of recreational facilities. For instance, Duncan et al. (2005) found a significant, positive association between the perceived presence of physical activity facilities and physical activity. One review revealed that a modest number of studies produced consistent findings that proximity to community recreational facilities is related to the recreational physical activity of adults (Humpel et al. 2002). However, there appears to be a gap in studies that consider the association between active transportation and the presence of recreational facilities.

Presence of trails significantly increased the likelihood of active transportation among participants in this study. Trails within neighborhoods provide a unique opportunity for physical activity; in fact, one study found that the use of trails was significantly associated with meeting physical activity recommendations (Deshpande et al. 2005). Our finding is consistent with several other studies that have found strong, significant associations between proximity to trails and recreational physical activity (Bauman and Bull 2007; Kaczynski and Henderson 2007). The greatest necessity for trails is that they exist within walking distance of people's homes, as Troped and colleagues (2001) observed that for every quarter mile increase in distance from people's homes, the likelihood of using the trail decreased by forty-two percent.

Much of the literature focusing on the proximity of trails and their use has examined the affect on recreational physical activity. However, findings from this study indicate that trails can be useful for utilitarian transport rather than just for recreation.

Social Capital and Aesthetics

The results of our study indicate that a well-maintained community is not a prerequisite for active transportation, since the likelihood of active transportation increased as the rating for community maintenance decreased. This may indicate that the act of utilitarian transportation does not require attractive surroundings; the surroundings merely provide a route. We did not find any objective associations between aesthetics and active transportation; however, this could be related to weakness in construct validity or percent agreement with the objective audit tool, as aesthetic questions are inherently are more subjective in nature (Malecki et al. 2013).

Urban vs. Non-Urban Predictors

Presence of destinations was a consistent predictor of active transportation in both urban and non-urban areas, which indicates that mixed-use developments are important considerations for urban, suburban, and rural communities. However, we only observed a significant association between the perceived presence of destinations and active transportation in non-urban areas. This could suggest that people living in urban areas may have a skewed notion of close proximity. Also, people living in urban areas who actively transport may have greater appreciation for physical activity facilities and amenities; thereby, they give their community a better ranking for physical activity.

An interesting story is presented in the non-urban areas, as we observed a significant, positive association with presence of bicycle supportive streets and active transportation that was not found in urban areas. This finding suggests that bicycle facilities are especially important in non-urban areas, or places where infrastructure investments may not already be a priority.

Strengths and Limitations

This study has certain limitations. It is cross-sectional and observational in nature; thus, we determine only correlations; we cannot infer causality of relationships. In addition, the questions that comprise the SHOW perceptions do not fully align with the objective measures obtained from the WASABE tool. Participants were asked about their "community" rather than their "neighborhood," while it is precisely the neighborhood that the WASABE instrument attempted to capture. Since the WASABE neighborhood is defined as a 400 meter radius around each participant's home, this limitation has the potential to conceal the importance of destinations slightly farther away, even if within walkable distance. Moreover, the active transportation component of SHOW relied on self-reported recall of individual active transportation over the past 30 days, and so is subject to recall bias, recall error, and potential overestimation of transportation physical activity. It is also important to note that this self-reporting did not differentiate between walking and bicycling. This may be misleading when associations between objective infrastructure supports of each mode of transportation are made. Use of an accelerometer, an objective measurement of active transportation, would reduce these limitations of self-reported physical activity.

Another limitation is the potential for "self-selection" of the residents, who may have intentionally chosen neighborhoods based on the existence of physical activity supports. In an attempt to control for this phenomenon, we used the length of residence in the home as a surrogate for self-selection. By controlling for length of residency, the chances decrease that the observed associations between the built environment and active transportation are explained by the prior self-selection of residents.

To add to its strengths, we examined populations of all ages and from many socio-economic groups and backgrounds, and who live in urban, suburban, and rural areas. However, the sample lacks ethnic diversity; most participants were white.

Our study methodically examined street-level environmental characteristics within a concentrated area surrounding SHOW participants' households. The objective information gathered is at much finer resolution than that gathered by GIS techniques such as Google Streetview or other satellite images. Each utilitarian destination was meticulously counted, each sidewalk presence was methodically recorded, bicycle-supportive streets were systematically documented, visible walking and bicycling trails were carefully observed, and other aesthetic features were thoroughly logged by trained observers at each site. This level of scrutiny provides more up-to-date and objective information than all other methods regarding the environmental features that may play a significant role in predicting active transportation behavior.

Conclusions

Findings from this study extend the current literature surrounding perceived and objective indicators of physical activity, and specifically add to the limited literature that focuses particularly on active transportation. This study supports the concept that people will be more likely to conduct active transport if they live in areas with more non-residential destinations; have access to more bikeable and walkable streets; live in close proximity to walking and bicycling trails; and generally perceive their community to have many destinations within close proximity. Our study confirms the notion that presence of built environment supports of active transportation are not attenuated by perceptions of the built environment. This further supports a "build it and they will come" approach to bicycle and pedestrian infrastructure and multi-use community design planning, and may be a successful local approach for communities. Our evidence suggests that policies that facilitate active transportation within the built environment should be implemented by providing or improving bicycling and walking infrastructure and by integrating mixed land-use/smart growth principals into common practice in urban and non-urban communities.

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Chapter 3

Incorporating Bikeability, Walkability, and Transit into an Active Transportation Index

Abstract:

Background: Evidence from public health, urban planning, and transportation has recently emphasized the importance of using objective measures of the built environment to better understand the relationships between attributes of the physical environment and physical activity behaviors. Walkability indices have been created to assess the suitability for walking for transportation and recreation; however, an index to assess the suitability for active transportation, or utilitarian walking or bicycling, has yet to be developed.

Aims: To create a composite "active transportation" index that includes both connectivity and proximity measures that builds off previous indices, but also includes measures of bikeability, walkability, and public transit; and to evaluate its power to predict active transportation more accurately than other metrics, such as Walkscore.com.

Methods: We developed an active transportation index (ATI) using data from the Survey of the Health of Wisconsin (SHOW), the Wisconsin Assessment of the Social and Built Environment (WASABE), an ancillary study of the SHOW, and other geographic information systems (GIS) sources. Multivariate logistic regression was used to assess the relationship between active transportation behavior and active transportation metrics.

Results: Our composite ATI was a better predictor of active transportation behaviors than Walkscore.com.

Conclusions: To our knowledge, no previous active transportation indices have been developed. Our ATI reveals the important synergistic relationship between proximity and connectivity measures, in addition to Bikeability, walkability, and public transit measures, in a comprehensive, composite active transportation index.

Introduction

Evidence from public health and urban planning and transportation has recently emphasized the importance of using objective measures of the built environment to better understand the relationships between attributes of the physical environment and physical activity behaviors (Leslie et al. 2007; Saelens et al. 2003; Sallis et al. 2004; Owen et al. 2004). Because walking is the most common adult physical activity (Siegel et al. 1995), research consistently focuses on the "walkability" of built environments, and on associating the walkability of places with health outcomes such as Body Mass Index (BMI) and cardiovascular disease. Therefore, walking is currently a target of environmental and policy initiatives in public health (Leslie et al. 2007; Sallis et al. 1998). The walkability of a community refers to the characteristics of the built environment that may be suitable for people to walk for leisure, exercise, recreation, travel to work, running errands or play (Leslie et al. 2007). However, most studies focus on walking for recreation or pleasure rather than to get to a destination, that is, walking for transport (Owen et al. 2004). Walking for transport presents an opportunity for physical activity to address the increasing epidemic of sedentary lifestyles. However, while walking is a very attractive option for transportation for many reasons, bicycling also offers benefits, and analysis of the "bikeability" of the built environment presents a promising research opportunity. Bikeability refers to the suitability of a place for bicycle use. Together, bicycling or walking for transport can be referred to as active transportation, or human-powered transport.

Previous walkability indices have used measures of urban design to rate the level of walkability, including land-use mix, residential density, and intersection density (Frank et al.

2004; Frank et al. 2010). A more popular option for determining walkability, that is both convenient and inexpensive, is the publicly available website, WalkScore.com. However, these tools have not included measures of urban configuration that include suitability for walking *and* bicycling. These measures include bicycle lanes and paths, the potential for multi-modal transportation through transit stops, or even sidewalks for walkability, all of which would further assess the linkages between the built environment and its potential for active transportation. Additionally, these types of walking and cycling infrastructure have been infrequently evaluated in relation to nonmotorized transport choice (Saelens et al. 2003). Furthermore, it is unclear whether or not walkability is an appropriate measure for overall active transportation (Grasser et al. 2012). We hypothesize that these built environment variables may have a synergistic effect on active transportation.

The purpose of this study is to create a composite "active transportation" index and to evaluate its power to predict active transportation more accurately than other metrics, such as Walkscore. This paper utilizes previous walkability indices (e.g. Frank et al., 2010; Krizek et al., 2003; Vargo et al., 2012) to create an index that incorporates net residential density, intersection density, land-use mix, transit stops, bike lanes, and sidewalks. The goal is to create a composite index that incorporates both GIS and Wisconsin Assessment of the Social and Built Environment (WASABE) data to compare levels of active transportation behavior by Surey of the Health of Wisconsin (SHOW) participants through an active transportation score. This can then be compared to WalkScore, which ranks neighborhoods on their suitability for walking.

Background

Walkability indices are historically based on measures that meet criteria for proximity and connectivity of different land uses. Proximity describes the nearness of destinations within an area, but does not consider the availability of a transportation system to connect them (Frank et al. 2003). Connectivity refers to the directness of links and the frequency of connections (e.g. intersections) in a transport network. This affects the degree to which these networks — streets, walking and cycling paths — connect people to their destinations. A highly connected network has many short links, numerous intersections, and few dead-ends. As connectivity increases, travel distances decrease and route options multiply, which allows more direct travel between destinations and creates a more accessible and resilient transportation system (TDM Encyclopedia, 2013). Good connectivity provides easy access to key destinations for pedestrians. Excellent connectivity actively seeks to discourage car use by making local trips easier and more pleasant by foot or by bike than by car (Frank et al. 2004). We used these two concepts, proximity and connectivity, to determine the active transportation index for this study. Rationale for our active transportation index is based on extensions of the Frank et al., 2010, Vargo et al., 2012, and Krizek et al., 2003 walkability indices.

Proximity parameters for our active transportation index include:

- household density; the ratio of the number of dwelling units to land area
- employment density; the ratio of retail employment to land area
- destinations; the number of retail destinations within the area

Connectivity parameters for our active transportation index include:

- intersection density; the ratio of the number of intersections to the land area

- transit stops; the presence or absence of public transit (bus or train) within the area
- sidewalks; the percentage of streets with sidewalks
- bicycle supportive streets; the percentage of streets with bike lanes or enough width to support coexisting bicycles and motor vehicles

Methods

Study Design

Three methods of data collection were utilized to test our active transportation index: (1) in-person interviews, self-administered questionnaires, computer-assisted surveys, physical measurements and laboratory tests of neighborhood residents as part of the Survey of the Health of Wisconsin (SHOW); (2) a neighborhood built environment audit to assess the objective physical environments as part of the Wisconsin Assessment of the Social and Built Environment (WASABE) survey; and (3) geographic information systems (GIS) data related to the addresses of participants in the study.

First, this work was completed as part of the statewide SHOW study, which queried Wisconsin residents about their physical and mental health history, demographics, behavioral, lifestyle, occupational, and household characteristics, and much more. SHOW participants also received a physical examination that included blood pressure, a blood draw, urine collection, and height and weight measurements (Nieto et al. 2010). Survey data also included home address, age, gender, race/ethnicity, education, marital status, Body Mass Index (BMI), household income, years of residency in household, diagnosis of chronic disease, and physical activity types and levels.

Second, as an ancillary study to SHOW, WASABE used a direct observation instrument developed and validated by SHOW investigators to assess neighborhood indicators of the physical and social environment surrounding participating households (REF). More information regarding the reliability, construct validity, and methods of the WASABE tool are in Malecki et al. 2013.

Using the WASABE instrument, neighborhood attributes were assessed within a 400 meter street-network buffer surrounding SHOW participants' homes. Specific built environment features captured by WASABE included retail destinations, intersections, transit stops, sidewalks, and bicycle supportive streets. Each of these variables was assessed and counted by field observers within the 400 meter neighborhood. The total number of retail destinations was the sum of grocery stores, gas stations, pharmacies, restaurants, banks, and coffee shops — identified as "neighborhood-scale trip ends" — in other words, all likely locations that would generate walking or bicycling trips (Vargo et al. 2012). Public transit was accounted for by the presence of transit stops within the buffer. The field observers counted intersections within the buffer. The percentage of street segments that mostly contained sidewalks and the percentage of bike lanes or roads wide enough to support coexisting bicycles and cars were also recorded.

Last, household and employment densities were determined using various GIS sources. Household density by census block group was provided by the Wisconsin Applied Population Laboratory from the 2010 U.S. Census. The number of retail employees per census block group was retrieved from the Longitudinal Employer Household Dynamics Origin-Destination Employment Statistics for 2009. Retail employment was defined using the two-digit North

American Industry Classification System (NAICS) codes for retail trade (44-45). Average block length was calculated using GIS data. These variables are described in Table 5.

The six calculated values for the active transportation index were normalized using a z-score. The z-score is computed by subtracting the mean from the value and dividing by the standard deviation: [(x - mean) / standard deviation].

The active transportation index (ATI) is calculated as follows:

[(z-score household density) + (z-score employee density) + (z-score destinations) + (2*z-score intersection density) + (z-score transit stops) + (z-score sidewalks) + (z-score bicycle supportive streets)]

Population density is among the most consistent positive predictors of walking trips (Cervero 1996; Ross and Dunning 1997; Saelens et al. 2003), and is used in other walkability indices (Frank et al. 2009). We use household density to represent this measure. Population and employment density have also been found to be independent positive predictors of walking rates for commuting and shopping purposes (Frank and Pivo 1994). Commuting to work by walking or bicycling has been found to be higher where commercial facilities exist nearby and there is closer proximity or accessibility of jobs and services (Cervero 1996) and (Kockelman 1997) (Hanson 1987). Employee density has been used as a proxy for land use mix (Krizek 2003). The intersection density z-score was weighted by a factor of 2 based on rationale from a previous study that highlighted the strong influence of intersection density and street connectivity on nonmotorized travel choices (Frank et al. 2009). Presence of sidewalks and bicycle paths have also been shown to increase the number of walking and cycling trips (Kitamura 1997). Lastly, presence of transit is included within this index because of the increased physical activity a person can gain from walking to and from transit (Besser and Dannenberg 2005). Thus, by combining these different built environment variables, the active transportation index is a composite measure or rating for the suitability of active transportation in a neighborhood. Composite indices are thought to be beneficial since they capture the interrelatedness of many built environment characteristics and minimize any spatial collinearity (Brownson et al. 2009).

Confounding Variables

We chose the following sociodemographic characteristics because they can be highly influential factors in nonmotorized transport behavior (Black 1990; Hess et al. 1999; Ross 2000; Saelens et al. 2003). Participants were asked about their age, gender, marital status, length of time residing at their current address, highest educational attainment, household income, race, and history of chronic disease. To determine a history of chronic disease, participants were asked if a physician had ever told them that they had hypertension, congestive heart failure, diabetes, high cholesterol or asthma. Measurements for body mass index (height and weight) were obtained by clinical exam. A total of 1,029 adults residing in Wisconsin were included in this study, of whom 326 utilized active transportation. Urbanicity classification was determined based on criteria from Miller and Hodges (1994) and Vargo et al. (2012). This urbanicity method distinguishes different patterns of urbanization intensity within and outside of metropolitan areas. It generates a three-tiered classification system of urban, suburban, and rural. Descriptive characteristics of the study population can be found in Table 6. We performed chi-squared tests to assess the relationship between the demographic variables and the outcome variable, active transportation.

Table 4 Active Transportation Index Variable Definitions

Variable	Operational Definition	Units	Source	Conceptual Definition	Proximity/ Connectivity
Employee (Retail) Density	Gross retail employment density calculated from census tracts that intersect the buffer around each SHOW household	# employees / census block group	US Census NAICS	Concentration of employees serves as a proxy for jobs and indicates the intensity of the land use with regard to commercial activity. This relates to trip generation for both residents and other employees to the area	Proximity
Household Density	Average household density calculated from block groups that intersect the buffer around each SHOW household	Households/ acre	US Census 2000	Concentration of residents in a place encourages other land uses to collocate and indicates the proximity of residents to each other. Increased density is also an indicator of shorter distances between destinations	Proximity
Retail Destinations	Number of retail destinations inside buffers around each SHOW household	# of destinations	WASABE	Directly measuring the types of commercial services involved in daily trips	Proximity
Intersection Density	Density of intersections inside buffers around each household	# of intersections / area of 400 m street network buffer	WASABE	Intersections measure the connectivity of the street network and thus the number of pathways possible for making walking trips and the directness of possible paths (variety of route options)	Connectivity
Transit Stops	Presence of bus and rail transit stops inside buffers around each SHOW household	Presence/ Absence of transit stops	WASABE	Transit connects people with destinations by facilitating trips that would otherwise be made by car. In addition, walking or bicycling to and from transit stops can serve as important components of recommended physical activity	Connectivity
Sidewalks	Percentage of street length with sidewalks	Percentage	WASABE	Sidewalks are the infrastructure, which facilitate walking trips. The presence of sidewalks on paths between origins and destinations can make walking a more attractive mode choice for trips	Connectivity
Bicycle Supportive Streets	Percentage of Streets with Bike Lanes and /or streets wide enough to support bicycles	Percentage	WASABE	Bicycle lanes facilitate bicycling trips; roads that are wide enough facilitate bicycling trips. The presence of bicycle lanes between origins and destinations can make bicycling a more attractive mode choice for trips	Connectivity

Adapted from Vargo et al. 2012

Outcome of Interest

The outcome of interest was active transportation. In the SHOW survey, participants provided information about whether they engaged in transportation activity (walking or bicycling as a means of getting to and from work, or school, or to do errands) over the past 30 days. Respondents specified the total amount of time (in minutes or hours) and number of days during the past month spent bicycling and walking. The minutes of active transportation activity were then converted to Metabolic Equivalent (MET) minutes, or the ratio of the rate of energy expended during an activity to the rate of energy expended at rest. A binary variable for active transportation was created, defined as whether or not active transport was conducted. The models were also tested using a more strict definition of active transportation, that is, whether participants met Physical Activity Guidelines for Americans (PAGA). The PAGA advisory committee concluded that the amount of energy expenditure necessary to achieve many of the health benefits from physical activity ranged between 500 – 1000 MET-minutes/week (U.S. DHHS 2008). "Active transporting as recommended" was defined as the accumulation of 500 MET-minutes/week.

Walkscore.com

Walkscore.com assesses neighborhood walkability by measuring resource proximity and density. Through a Google search algorithm that locates resources within a one-mile radius of a user's address, preserving confidentiality, scores are the summed total of these resources, weighted by their distances from the address, and range from 0 to 100. Resources include grocery stores, bars, movie theaters, libraries, schools, and more. Scores do not distinguish "health-friendly" resources from other types, and do not incorporate aspects like area crime, sidewalk quality, or street connectivity (Carr 2011).

Statistical Analysis

We employed multivariate logistic regression to test the impacts of the ATI on active transportation. The regression models were adjusted for demographic characteristics (age, gender, education, household income, body mass index (BMI), chronic disease status, urbanicity classification, race/ethnicity, physical activity, and marital status). Age (21-74) and BMI (17-67) were included in the model as continuous variables. Gender, marital status (married or living with a partner vs. unmarried), race/ethnicity (white vs. Hispanic and nonwhite), physical activity (MET minutes per week score of at least 600), and chronic disease status were considered binary variables. Education and household income were categorical variables as determined by SHOW experts (Nieto et al. 2010). Urbanicity was also considered as a categorical variable (urban, suburban, and rural).

Correlation between the AT Index and Walkscore.com was conducted using both a Spearman's Correlation Coefficient (0.8394; $p<0.0001$) and a Pearson's Correlation Coefficient (0.8261; $p<0.0001$). Both the AT Index and Walkscore.com were normally distributed. Walkscore values ranged from 0 – 100; while the AT index values ranged from -6.5 – 15.3.

Results

The final sample included 1,029 participants from 689 households. The distribution of gender, race/ethnicity, age, educational attainment, chronic diseases status, and income is provided for the total sample (Table 6). There were 458 males and 571 females considered in the study, with each gender having 163 people actively transporting, for a total of 326 (roughly one-third of the study population). The majority of participants in this study were of non-Hispanic white ethnicity: about 88 percent of those participating in active transport were white.

Multivariate odds ratios for the composite ATI (Table 7) showed significantly positive associations with the individual's likelihood of actively transporting (aOR=1.134, 95%CI: 1.07, 1.20; $p<0.0001$). Results indicate that for every unit of increase in the composite scores that measure suitability for active transportation in the neighborhood, the odds for an individual to conduct active transportation increase by 13%. This holds for individuals who utilize any amount of active transport, in the range from 30 MET/week to approximately 14,000 MET/week. Multivariate odds ratios for walkscore.com for the same population (Table 7) also showed significantly positive associations with the individual's likelihood of actively transporting (aOR=1.025, 95% CI: 1.02-1.04; $p<0.0001$). However, the results for walkscore.com are substantially less robust; for every unit of increase in walkscore.com that measures walkability in the neighborhood, individuals are approximately two percent more likely to actively transport.

When conducting the multivariate logistic regression for only those meeting the physical activity recommendations (>500 MET/week), the adjusted odds ratio for the active transportation index decreased from 1.134 to 1.111 (95% CI: 1.03, 1.21; $p=0.0106$); whereas, the walkscore.com odds ratio changed negligibly from 1.025 to 1.022 (95% CI: 1.01, 1.04; p<0.0001) (Table 8).

Table 5 Descriptive Characteristics of Study Population, Including Active Transportation (AT) Levels

Study Population	~1029		~326		
Sample Characteristics	**N**	**% of Sample**	**N = # AT**	**% AT**	**AT X^2**
Gender					0.0188
Male	458	44.5%	163	35.6%	
Female	571	55.5%	163	28.5%	
Age					<0.0001
21-30	184	17.9%	91	49.5%	
31-40	171	16.6%	47	27.5%	
41-50	222	21.6%	62	27.9%	
51-60	242	23.5%	65	26.9%	
61-75	209	20.3%	61	29.2%	
Race/Ethnicity					0.0026
White	939	91.5%	285	30.4%	
Non-White	87	8.5%	39	44.8%	
Marital Status					<0.0001
Married, lives with partner	673	65.6%	175	26.0%	
Not Married	353	34.4%	150	42.5%	
Education					0.1401
High school graduate or less	23	2.3%	7	30.4%	
Some college	612	62.3%	181	29.6%	
College or beyond	348	35.4%	125	35.9%	
Family Income					<0.0001
Above 100% Federal Poverty Level	877	87.6%	64	7.3%	
Below 100% Federal Poverty Level	254	12.4%	124	48.8%	
Residency in Household					<0.0001
3 or more years	737	73.0%	207	28.1%	
Less than 3 years	273	27.0%	114	41.8%	
Body Mass Index					0.002
<25	380	36.9%	129	33.9%	
25< BMI <35	307	29.8%	112	36.5%	
>35	342	33.2%	85	24.9%	
Chronic Disease Status					0.5273
Without	403	43.7%	125	31.0%	
With	519	56.3%	171	32.9%	
Physically Active					<0.0001
Yes	642	64.5%	261	40.7%	
No	354	35.5%	58	16.4%	
Urbanicity Classification					<0.001
Urban	127	12.3%	63	49.6%	
Suburban	385	37.4%	143	37.1%	
Rural	517	50.2%	120	23.2%	

Table 6 Active Transportation Index vs. Walkscore.com

	Model 1: Adjusted for Confounding with AT Index				Model 2: Adjusted for Confounding with Walkscore.com			
Parameter	**aOR**	**5% CI**	**95% CI**	**p-value**	**aOR**	**5% CI**	**95% CI**	**p-value**
Urbanicity				0.2555				0.7821
Urban	1.000				1.000			
Rural	1.891	0.81	4.41		1.271	0.63	2.58	
Suburban	1.648	0.89	3.05		1.201	0.67	2.14	
Years in Home	1.007	0.99	1.03	0.5331	1.009	0.99	1.03	
Gender				0.4984				0.3354
Female	1.000				1.000			
Male	1.145	0.77	1.70		1.214	0.82	1.80	
BMI				0.7072				0.7702
Normal	1.000				1.000			
Obese	0.861	0.53	1.40		0.867	0.53	1.42	
Overweight	1.068	0.67	1.71		1.042	0.65	1.67	
Age	**0.98****	0.96	1.00	0.0292	**0.982****	0.96	1.00	0.0446
Race/Ethnicity				0.2579				0.2226
Non-Hispanic White	1.000				1.000			
Non-White	1.514	0.74	3.10		1.562	0.76	3.20	
Income				0.5186				0.5699
Education	**1.255****	1.08	1.46	0.0033	**1.219****	1.05	1.42	0.0103
Marital Status				0.5491				
Married	1.000				1.000			0.6981
Not Married	1.168	0.70	1.94		1.106	0.66	1.84	
Chronic Disease Status				0.1493				0.179
No Diagnosis	1.000				1.000			
Chronic Disease Diagnosis	1.369	0.89	2.10		1.343	0.87	2.07	
Physically Active				0.0002				<0.0001
No	1.000				1.000			
Yes	**2.596****	1.58	4.27		**2.695**	1.64	4.43	
index	**1.134****	1.07	1.20	<0.0001				
Walkscore.com					**1.025****	1.02	1.04	<0.0001

**=p<0.05

Table 7 Meeting MET Recommendations for AT vs. ATI or Walkscore.com

	Model 3: AT Meeting Recommendations of 500 MET-min/Week: Adjusted for Confounding and AT Index				**Model 4: AT Meeting Recommendations of 500 MET-min/Week: Adjusted for Confounding and Walkscore**			
Parameter	**aOR**	**5% CI**	**95% CI**	**p-value**	**aOR**	**5% CI**	**95% CI**	**p-value**
Urbanicity				0.3867				0.5316
Urban	1				1			
Rural	2.359	0.70	7.99		1.75	0.64	4.77	
Suburban	1.576	0.65	3.80		1.276	0.55	2.96	
Years in Home	1.017	0.99	1.05	0.2625	1.02	0.99	1.05	0.1958
Gender				0.2366				0.1891
Female	1				1			
Male	1.406	0.80	2.47		1.465	0.83	2.59	
BMI				0.5768				0.6217
Normal	1				1			
Obese	0.686	0.34	1.39		0.705	0.35	1.43	
Overweight	0.884	0.45	1.74		0.862	0.44	1.70	
Age	0.981	0.96	1.01	0.1517	0.982	0.96	1.01	0.1819
Race/Ethnicity				0.3915				0.2989
Non-Hispanic White	1				1			
Non-White	1.529	0.58	4.04		1.677	0.63	4.45	
Income				0.9321				0.9182
Education	1.146	0.92	1.42	0.2178	1.128	0.91	1.40	0.2759
Marital Status				0.2017				0.199
Married	1				1			
Not Married	1.604	0.78	3.31		1.609	0.78	3.33	
Chronic Disease Status				0.3553				0.4095
No Diagnosis	1				1			
Chronic Disease Diagnosis	1.333	0.73	2.45		1.295	0.70	2.39	
Physically Active				0.0045				0.0033
No	1				1			
Yes	**3.082****	1.42	6.70		**3.217****	1.48	7.01	
index	**1.111****	1.03	1.21	0.0106				
Walkscore.com					**1.022****	1.01	1.04	0.001

**=p<0.05

Discussion

Our findings show stronger associations between our index and active transportation than the free, open-source web-based tool, walkscore.com. Our index was about six times better at predicting any active transportation behavior than walkscore.com. When testing for levels of active transportation meeting national standards for physical activity, our index is a much stronger predictor of active transportation. These findings imply that our comprehensive, composite index of the built environment, one that includes measures of proximity and connectivity, is more effective at measuring active transportation than walkscore.com, which includes only measures of proximity. While walkscore.com is useful for people to evaluate their neighborhood for proximity to destinations, it fails to fully assess the connectedness and accessibility of streets, bike lanes, sidewalks, or transit. Users of walkscore.com may not understand the full potential (or lack thereof) of their neighborhood to support their ability to actively transport. Thus, our ATI may be slightly more effective at predicting who will actively transport in their built environment.

Our study is the first of its kind to incorporate bicycle paths, sidewalks, and transit stops into a composite index for active travel. By adding these variables to the index, it gives a more complete picture of the important role that these measures play in active transportation. Though it may not always be feasible and it is time-consuming to obtain information on presence of sidewalks, bicycle lanes, and transit stops, these are key features within an active living environment that should be included into the assessment. Our findings show that this micro-level data on these specific physical attributes provides a more comprehensive picture of the role on the environment on active transportation behavior.

One strength of this study is that the potential confounding factors, sociodemographic characteristics, were obtained on the individual level from SHOW. To ensure more reliable measurements, SHOW staff measured participant height and weight. Whereas, most other studies of the built environment and BMI use participants' self-reported height and weight to calculate BMI, which has the potential for introducing measurement error (McDonald et al. 2011; Papas et al. 2007).

However, this study does have its limitations – first, this study is cross-sectional, and we cannot establish a causal relationship between the built environment and active transportation. And despite the positive associations between the index and active transportation, some concern still remains related to self-selection into neighborhoods. We used the length of residence in the home as a surrogate for self-selection, in an effort to control for this phenomenon.

Participants in this study may also be subject to reporting bias when asked to state amounts of physical activity levels. Reporting bias occurs when a subject is reluctant to disclose an exposure or over-reports an exposure because of attitudes, beliefs, perceptions, or stigmas (Gordis 2009). In the case of our study, we were specifically looking at amounts of active transportation, and the participants may have over-reported their levels of bicycling or walking for transport (their exposure) because they believed that is an amount of which someone else (the questioner or society, perhaps) would approve.

The use of a composite AT index reduces opportunity for collinearity and over-adjustment; however, it may be less useful for intervention (Feng et al. 2010). In a composite index, it is unfeasible to identify which component can be identified as the highest priority.

In situations where observational data collection is infeasible or cost-prohibitive, our ATI could incorporate data from aerial photographs of high resolution satellite data exists. Thus, this ATI is generalizeable. Vargo et al. (2012) successfully used Google imagery and spatial databases to assess the association between the design of the built environment and walking outcomes. However, for studies larger in scope, this might be time-consuming.

Our study supports the importance of policies to support built environment infrastructure changes. Researchers have concluded sufficient evidence purports that community-scale land use regulations and policies can be effective in increasing walking and bicycling (Brownson et al. 2006).

Conclusion

A comparison of our active transportation index — which includes proximity and connectivity measures and an emphasis on built environment features that foster active transportation — to walkscore.com, which includes only proximity measures, we establish that both proximity and connectivity need to be considered when making decisions about urban planning and design. Our findings support policy initiatives that support multi-use zoning to increase accessibility of residential and non-residential destinations alongside those initiatives that support accessibility for all modes of transportation, motorized and non-motorized.

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Chapter 4

Air Quality and Exercise-Related Health Benefits from Reduced Car Travel in the Midwestern United States

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Abstract

Background: Automobile exhaust contains precursors to ozone and fine particulate matter (PM ≤ 2.5 µm in aerodynamic diameter; $PM_{2.5}$), posing health risks. Dependency on car commuting also reduces physical fitness opportunities.

Objective: In this study we sought to quantify benefits from reducing automobile usage for short urban and suburban trips.

Methods: We simulated census-tract level changes in hourly pollutant concentrations from the elimination of automobile round trips ≤ 8 km in 11 metropolitan areas in the upper midwestern United States using the Community Multiscale Air Quality (CMAQ) model. Next, we estimated annual changes in health outcomes and monetary costs expected from pollution changes using the U.S. Environmental Protection Agency Benefits Mapping Analysis Program (BenMAP). In addition, we used the World Health Organization Health Economic Assessment Tool (HEAT) to calculate benefits of increased physical activity if 50% of short trips were made by bicycle.

Results: We estimate that, by eliminating these short automobile trips, annual average urban $PM_{2.5}$ would decline by 0.1 µg/m^3 and that summer ozone (O_3) would increase slightly in cities but decline regionally, resulting in net health benefits of $4.94 billion/year [95% confidence interval (CI): $0.2 billion, $13.5 billion), with 25% of $PM_{2.5}$and most O_3 benefits to populations outside metropolitan areas. Across the study region of approximately 31.3 million people and 37,000 total square miles, mortality would decline by approximately 1,295 deaths/year (95% CI: 912, 1,636) because of improved air quality and increased exercise. Making 50% of short trips by bicycle would yield savings of approximately $3.8 billion/year from avoided mortality and reduced health care costs (95% CI: $2.7 billion, $5.0 billion]. We estimate that the combined benefits of improved air quality and physical fitness would exceed $8 billion/year.

Conclusions: Our findings suggest that significant health and economic benefits are possible if bicycling replaces short car trips. Less dependence on automobiles in urban areas would also improve health in downwind rural settings.

Key words: air pollution, BenMAP, bicycling, built environment, climate change, ozone, particulate matter, physical activity, urban design, vehicle emissions. Environ Health Perspect 120:68-76 (2012). http://dx.doi.org/10.1289/ehp.1103440 [Online 2 November 2011]

Introduction

The current fossil fuel-based transportation system of the United States negatively impacts human health by increasing air pollution and automobile accidents and by decreasing physical activity. Here, we consider how replacing short automobile trips with bicycle transport might yield health benefits through improved air quality and physical fitness, with a focus on the upper midwestern United States as our study region.

Both ozone (O_3) and fine particular matter ≤ 2.5 μm in aerodynamic diameter ($PM_{2.5}$) in the ambient air exacerbate bronchitis and asthma and may contribute to cardio- vascular mortality (Brunekreef and Holgate 2002). Asthma affects 8.2% of U.S. citizens, and an estimated 10 million adults have diagnosed chronic obstructive pulmonary disease (COPD) (Centers for Disease Control and Prevention 2009). In addition, recent estimates attribute 63,000-88,000 premature deaths per year due to $PM_{2.5}$ [U.S. Environmental Protection Agency (EPA) 2010c]. In the United States, on-road vehicles are responsible for about 26% of volatile organic compounds (VOCs) and 35% of nitrogen oxide (NOx) emissions (U.S. EPA 2005c, 2005d). NOx and VOCs combine to form O_3 and contribute to nitrate and secondary organic aerosols, important components of $PM_{2.5}$. Nearly 240 U.S. counties, with > 118 million total residents, exceeded U.S. EPA O_3 standards in 2011, and > 200 counties (> 88 million total residents) failed to meet $PM_{2.5}$ standards, in part because of pollution from short car trips (U.S. EPA 2011a, 2011b).

Transport-related inactivity, that is, the use of motorized transport rather than walking and bicycling, has been linked to increased mortality and decreases in healthy life years, with the greatest impacts on chronic diseases including heart disease, stroke, colon cancer, diabetes mellitus type 2, obesity, breast cancer, and osteoporosis [World Health Organization (WHO) 2002]. Carlson et al. (2009) estimated that 32.4% of the U.S. population is fully inactive (no moderate-intensity or vigorous-intensity physical activity lasting at least 10 min at a time), while only 33.5% is physically active, defined as 30 min/day with moderate-intensity activity, ≥ 5 days/week. In a recent Dutch study, Johan de Hartog et al. (2010) concluded that shifting from short car trips to bicycle trips would reduce all-cause mortality, with estimated reductions in mortality due to increased physical activity that were nine times greater than estimated increases in mortality due to increased pollution inhalation and traffic-related fatality estimates in the Netherlands.

In the United States, 28% of all car trips are ≤ 1.6 km (1 mi), which is the distance that a typical European would walk (European Commission 2001; Pucher and Dijkstra 2003). Another 41% of all trips are ≤ 3.2 km (2 mi), a distance that many Europeans would be as likely to bicycle as to walk (European Commission 2001; Pucher and Dijkstra 2003). If we use European travel behavior as a point of comparison for walking and bicycling activity for the United States, these data suggest that many car trips in the United States could be avoided. Amplifying the potential benefits of increased bicycle use is the nonlinear relation- ship of vehicle emissions to travel time. A large fraction of emissions (25% of VOC and 19% of primary $PM_{2.5}$) are emitted in just the first few minutes of automobile operation, often known as "cold start," before pollution- control devices operate [Federal Highway Administration (FHWA) 2006]. Because emissions control systems reach operating temperature only after several miles of travel and typically cool below operating range in < 1 hr (Singer et al. 1999), reducing the number of short trips could disproportionately curtail pollutant emissions from on-road vehicles.

In the present study, we quantified the potential health and monetary benefits of replacing short (≤ 4 km one way) car trips with travel by bicycle (50% of trips) in the 11 largest midwestern metropolitan statistical areas (MSAs): Chicago, Illinois; Cincinnati, Cleveland, Columbus, and Dayton, Ohio; Detroit and Grand Rapids, Michigan; Indianapolis, Indiana; Madison and Milwaukee, Wisconsin; and Minneapolis/ St. Paul, Minnesota. This study builds on the Projected Land Use and Transportation (PLUTO) modeling framework developed by Stone et al. (2007). We estimated changes in regional emissions and air quality, as well as resulting health benefits, across the upper midwestern states [see Supplemental Material, Figure 1 (http://dx.doi.org/10.1289/ ehp.1103440) for a map of the area]. In addition, we estimated the benefits of increased physical activity using the Health Economic Assessment Tool (HEAT) for cycling developed by the WHO (Rutter et al. 2007).

Methods

We estimated that eliminating short car trips (≤ 8 km round trip) in urban areas of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin would reduce residential vehicle use by 20%. This estimate is based on a census- tract level travel and mobile emissions inventory by Stone et al. (2007), who combined 1995 Nationwide Personal Transportation Survey (NPTS) responses (FHWA 1997), demographic modeling of household vehicle travel, and the U.S. EPA MOBILE6 emissions factor model (U.S. EPA 2004b). From that contemporary emissions inventory, we estimated current emissions levels if all round trips of ≤

8 km in urban and suburban census tracts were made using alternate modes of transportation. To inform the potential impact of a range of realistic policies and choices, we used these estimated reductions to quantify the maximum potential response to a change in travel behavior. Although arbitrary, this assumed reduction in short auto trips would be consistent with the use of active (cycling or walking) transportation in European cities similar in density and population to the MSAs considered here. These values represent theoretical upper bounds on short-trip transportation choices under current travel patterns and population density. We assume that no change occurs in rural travel because distances between residential and commercial areas are typically too great for bicycling or walking and because rural populations are too low to support mass transportation.

Specifically, we compared transportation modes used in the study-area cities, with populations ranging from 837 persons/km^2 in Grand Rapids to 4,884 persons/km^2 in Chicago (average 2,051 persons/km^2), to five European cities with similar population densities (range 901-5,971, average 2,910 persons/ km^2) [see Supplemental Material, Table 1 (http://dx.doi.org/10.1289/ehp.1103440)]. Although public transportation use was similar, only 39% of trips were made by auto- mobile in the European cities, compared with 80% of trips in the Great Lakes region. Although the configurations and historical growth patterns of the European cities differ from their American counterparts, the fact that half of all trips used active transportation suggests that active transport for 50% of short trips is feasible for similar travel distances in midsized American cities of similar density and that greater active transportation need not be limited to areas of highest density.

We estimated changes in emissions only for on-road light-duty passenger vehicles with internal combustion engines and only for round trips ≤ 8 km. We modeled changes in primary emissions (including NOx, carbon monoxide, sulfur dioxide, ammonia, VOCs, elemental carbon, organic carbon, and primary fine and coarse particulate matter) from all stages of vehicle operation, as well as emissions from evaporation, brake dust, resuspended road dust, and refueling. Reducing the number of short trips further lessens the frequency of cold starts from 59.9% to 21.9% of trips in urban tracts and from 55.6% to 20.3% in suburban tracts, with corresponding reductions in VOC and NOx emissions. We mapped emissions from the census-tract level to the 12×12 km^2 model grid by area- weighted averaging using the U.S. EPA Sparse Matrix Operator Kernel Emissions (SMOKE) model, version 2.4 (Community Modeling and Analysis System Center 2007). Emissions from sources other than motor vehicles were from the 2001 National Emissions Inventory (U.S. EPA 2005a) and were held constant in both scenarios.

We estimated changes in ambient air $PM_{2.5}$ and O_3 concentrations using hourly regional chemical transport simulations with the Community Multiscale Air Quality Model (CMAQ), version 4.6 (Byun and Schere 2006), driven by meteorology from the weather research and forecasting model for the full year of 2002 (Skamarock and Klemp 2008; Skamarock et al. 2008). Simulations with CMAQ were conducted on a 12×12 km^2 grid and included gas phase, aqueous, and heterogeneous chemical reactions and equilibrium aerosol thermodynamics. We followed the model configuration used by Spak and Holloway (2009), with boundary conditions from a 36×36 km^2 simulation over continental North America.

We used the Environmental Benefits Mapping and Analysis Program (BenMAP) version 4.0.35 (U.S. EPA 2010a) to estimate health impacts due to CMAQ-simulated changes in ambient air pollution resulting from reduced car travel. Because BenMAP addresses both mobile and stationary sources (U.S. EPA 2004a, 2008), it has been used to support the creation of environmental regulations in several countries.

After air quality data is loaded into BenMAP, the program determines the change in ambient air pollution. BenMAP then uses concentration-response functions (CR) to calculate the relationship between the pollution and certain health effects, applying the relationship to the exposed population (Abt Associates 2010). Finally, BenMAP uses a "damage function" to estimate health costs and benefits from changes in air quality. A damage function quantifies the health benefits and economic value of reduced exposure to pollutants (Davidson et al. 2007).

BenMAP 4.0 (i.e., version 4.0.35) incorporates hourly air pollution data and county-level baseline incidence rates for the following health outcomes: overall mortality, asthma exacerbations, chronic bronchitis, hospital admissions, acute myocardial infarctions, acute and chronic respiratory infections, upper and lower respiratory infections, work-loss days, and school-loss days. Spatial specificity in base- line incidence data varies by health outcome and location; where county-level data are not available, BenMAP distributes state estimates to the county level using age-specific rates for each health outcome within each county. For mortality estimates, BenMAP combines national-level census mortality rate projections and county-level age-specific incidence rates from 2006 with projected changes in study area populations to derive county- level mortality rate projections for 2010. For the present study, BenMAP used state-level hospitalization data to estimate county-level incidence for Minneapolis/St. Paul, Chicago, and Indianapolis; county-level incidence data for all cities in Ohio; and city hospital discharge data for Milwaukee, Madison, Detroit, and Grand Rapids. For emergency room (ER) admissions, we used midwest regional incidence data for Detroit, Grand Rapids, Chicago, and Indianapolis; state-level data for Minneapolis/St. Paul; county-level data for Ohio cities; and hospital discharge-level data for Milwaukee and Madison. For all cities, nonfatal acute myocardial infarction incidence rates were based on regional hospitalization data. All other health end point data were based on national figures.

BenMAP assigns monetary values to the reduction of adverse health effects based on national averages that do not reflect intracity or intercity variability in costs. The BenMAP analysis was conducted on the 12 × 12 km^2 grid, using 2010 census projection allocation to the grid by the U.S. EPA. Valuation is in 2010 dollars. We combined air quality estimates for 2002 from CMAQ with 2002 U.S. EPA monitoring using spatial scaling by Voronoi nearest neighbor averaging (e.g., Chen et al. 2004). This pairing yields air quality inputs to BenMAP including complete spatial and temporal coverage by high-resolution hourly modeling, constrained to match concentrations observed near monitors. We then used the expert-derived $PM_{2.5}$ CR functions, valuation estimates, and pooling methods used for the U.S. EPA 2006 Regulatory Impact Analysis, plus O_3 exposure-response functions for 2008 National Ambient Air Quality Standard (NAAQS) evaluations (U.S. EPA 2004a, 2008; University of North Carolina Institute for the Environment, Community Modeling and Analysis System Center 2008). Because multiple studies exist for each given health incidence, pooling techniques are often used to statistically combine the results. Using BenMAP, we ran each CR function and pooling of incidence and valuation for each health end point in a 5,000-member Monte Carlo ensemble. Sources of CR functions used in this analysis are presented in Tables 8 and 9. As standard practice, the U.S. EPA does not pool mortality studies. Thus, we used the Harvard Six Cities study (Pope et al. 2002) as BenMAP input for $PM_{2.5}$ mortality; that study included the most representative sites. We selected the 2010 population database to use in BenMAP because the sensitivity studies we conducted indicated that choice of year has no substantial impact (1-2% difference) on incidence of health threats.

To address the potential health and economic co-benefits that would result if half of all short trips were made by bicycle, we used HEAT. This model uses relative risk data (Anderson et al. 2000) to estimate cost savings from reduced all-cause mortality. Controlling for socioeconomic variables (e.g., age, sex, smoking) and leisure time activity, HEAT calculates risk reduction for days spent cycling based on estimates of total number of days cycled, distance, and average speed (Rutter et al. 2007).

We used HEAT analysis to estimate the monetized health benefits associated with the conversion of one-half of short trips (< 8 km round trip) by car to be made by bicycle. This represents 10% of vehicle miles traveled (VMT) for the region. We used the U.S. EPA value of a statistical life ($7.4 million) (U.S. EPA 2010b) and the annual percentage of all-cause working-age mortality [0.00390; 95% confidence interval (CI): 0.00277, 0.00503] (Wilkinson and Pickett 2008). We assumed an average of 124 days of cycling per year, HEAT's default value (Rutter et al. 2007), which is representative of the climate of the upper midwest, where bicycle commuting is most common from April through October. We also assumed that only 50% of these trips would be undertaken by people who do not currently cycle, thus excluding the small percentage of the population already benefitting from cycling, as well as elderly individuals or those physically unable to bicycle. We used the NPTS average commute distance for each MSA (from 3.34 to 3.98 km) with an average speed for commuter cyclists of 14 kph. Finally, we used the HEAT-recommended default percentage (90%) of cyclists completing a round trip each day.

Results

Simulations yielded unique hourly estimates of surface-level $PM_{2.5}$ throughout the year (Figure 5A) and O_3 during the warm season (1 May 30-September) (Figure 5C) on a 12 × 12 km^2 grid for 2002. The CMAQ simulations described here captured spatial and temporal variability in $PM_{2.5}$ [see Supplemental Material, Table 2 (http://dx.doi.org/10.1289/ehp.1103440)] and O_3 (see Supplemental Material, Table 3) when compared with U.S. EPA monitoring data throughout the region, with performance for $PM_{2.5}$ and O_3 both exceeding community and U.S. EPA expectations for chemical transport modeling in policy and research applications.

We estimated that substitution of non- emitting modes for short trips would achieve average annual reductions in the 24-hr average $PM_{2.5}$ concentrations considered in U.S. $PM_{2.5}$ regulations (Figure 5B. Regional O_3 would also be reduced throughout the May- September summer season (calculated based on daily maximum 8 -hr and 1-hr averages, consistent with U.S. O_3 regulations) but day- time O_3 would increase in the largest cities because of VOC-limited O_3 production conditions in urban environments (Figure 5D). Effects of transportation on O_3 concentrations within the MSAs are complex because of the nonlinear interplay of emissions and meteorology in atmospheric chemistry and transport, whereby local ambient O_3 concentrations often increase in response to reductions in NOx and/or VOC emissions (Sillman 1995). In our emissions inventory, motor vehicles were responsible for most of the NOx (70-98%) and VOC (40-95%) emissions in the MSAs, with the highest percentages of emissions from motor vehicles in the most urbanized areas. Although Figure 5B and D show long-term averages (annual for $PM_{2.5}$ and summer for O_3), we used hourly values from CMAQ to estimate the potential health benefits of increased active transport.

Fine particulates ($PM_{2.5}$).

We observed changes in $PM_{2.5}$ and O_3, associated health outcomes, and monetary savings for each MSA and for the combined total of all grid cells out- side the 11 MSAs (Tables 8 and 9). We estimated that eliminating short car trips would reduce annual average $PM_{2.5}$ across the study region by 0.08-0.15 $\mu g/m^3$ (1.0-2.0%) in most MSA urban centers. In the upwind MSAs of Madison and Minneapolis/St. Paul, which would see little benefit from $PM_{2.5}$ reductions in other cities, we estimated that $PM_{2.5}$ would be reduced by 0.05 $\mu g/m^3$ (Figure 5B). Nearly all of the estimated reduction in $PM_{2.5}$ would be due to decreases in secondary aerosols, especially nitrate formed from NOx and secondary organic aerosols from VOCs. Primary particle emissions from motor vehicles are negligible, so the reduced VMT scenario would not significantly affect this smaller fraction of $PM_{2.5}$ mass.

Reductions in $PM_{2.5}$ in urban areas and downwind would be greatest during high-pollution episodes exceeding the 24-hr average $PM_{2.5}$ NAAQS. In urban grid cells, the average estimated reduction during NAAQS exceedances was 0.20 $\mu g/m^3$, equivalent to the maximum change in annual average $PM_{2.5}$ in Chicago [see Supplemental Table 4 http://dx.doi.org/10.1289/ehp.1103440)]. In addition, we estimated that the reduction in short auto trips would result in one fewer exceedance per year in a typical urban grid cell and a 5-25% reduction in the number of annual exceedances. Our results indicate that adverse health outcomes related to $PM_{2.5}$ would be reduced in all MSAs (Table 8). Reductions in $PM_{2.5}$-related mortality across the midwest are shown in Figure 6A, with the total impact across the 37,000-mi2 region being 525 fewer deaths. We estimated that asthma exacerbations would decrease annually by > 2,500 cases. In addition, there would be approximately 100 fewer COPD cases, whereas net respiratory symptoms, hospital admissions, and ER visits would decrease by 94,186 cases annually.

Regarding cardiovascular disease, there would be approximately 860 fewer cases of nonfatal acute myocardial infarction and hospital admissions. Savings from reduced annual mortality would reach almost $4.14 billion. Savings of > $7.5 million would result from fewer respiratory cases, hospital admissions, and ER visits, whereas a reduction in COPD would save > $39 million per year; reductions in nonfatal acute myocardial infarctions and cardiovascular hospitalizations would save > $54 million. We estimate that total savings from reducing adverse health effects due to $PM_{2.5}$ would be about $4.25 billion/year (95% CI: $598 million-$11.2 billion). Projections suggest that $PM_{2.5}$ exposure would also be reduced in populations outside MSAs and that resulting reductions in adverse health effects would account for roughly 25% of the total benefit.

Ozone.

Estimated effects of eliminating short car trips on O_3 pollution vary in relation to the size and density of urban areas. For large urban areas, estimated daily 8-hr maximum, 1-hr maximum, and daily average O_3 concentrations during the May-September O_3 season generally increased in city centers, whereas concentrations decreased in suburbs, some smaller urban areas, and in areas down- wind of the MSAs (Figure 5D). Simulated changes in transportation and reductions in cold-start frequency would decrease total NOx emissions by 5-12% and total VOC emissions by 10-25%.

Although we estimate that NOx and VOCs would both be reduced, the response to NOx reductions would be more pronounced, resulting in increased O_3 in urban cores, consistent with previous studies in the region (Sillman 1995). Changes in estimated O_3 concentrations were greater during the warmest months (July-August) when concentrations are highest, with increases and decreases of up to 2 ppb. We estimate that daily 8-hr maximum O_3 would increase on a population-weighted basis (Table 9) but that area-averaged O_3 levels would decrease in every MSA. BenMAP analysis indicated net regional savings from declines in mortality, school-loss days, hospitalizations, ER visits, and acute respiratory symptoms, but some increases in costs in cities such as Chicago, Cleveland, Columbus, Milwaukee, and Minneapolis/St. Paul due to changes in O_3 levels. Costs resulting from O_3 increases due to reduced VMT were statistically significant for only Chicago and Minneapolis/St. Paul, but estimated savings from $PM_{2.5}$ reductions were greater than increased costs due to O_3 in all cities.

We estimated that areas outside the MSAs would experience net benefits for all O_3-related health outcomes. For nine of the cities (excluding Chicago and Minneapolis/St. Paul), we estimated a potential reduction of approximately 30,000 cases in acute respiratory symptoms associated with the potential changes in O_3 (resulting in savings of almost $1.9 million) and 8,632 fewer school-loss days (savings of almost $822,000). This distinct reduction in acute respiratory symptoms to areas outside the MSAs is shown in Figure 6B.

Estimated changes in health outcomes due to changes in O_3 are less correlated with MSA density or size than estimated changes due to reduced $PM_{2.5}$, particularly for outcomes related to daily peak values, such as acute respiratory symptoms. Instead, estimated changes in O_3-related health impacts were often more pronounced in smaller MSAs such as Dayton and Grand Rapids, reflecting differences in total VOC:NOx ratios and the degree to which reductions in local motor vehicle emissions would alter them. Thus, estimated effects of eliminating short car trips on population O_3 exposures are highly sensitive to urban size, density, and travel patterns.

Benefit from physical activity.

Based on WHO HEAT analysis, we estimated that completing 50% of short trips by bicycle would result in average annual savings of > $2.5 billion for short suburban bicycle trips and nearly $1.25 billion for short urban trips (Table 10), for a total of approximately $3.8 billion in benefits across an estimated population of 2 million people and a reduction in premature mortality of almost 700 deaths/year.

Discussion

In the study region with a population of 31.3 million, we estimated that eliminating short car trips and completing 50% of them by bicycle would result in mortality declines of approximately 1,295 deaths/year (95% CI: 912, 1,636), including 608 fewer deaths due to improved air quality and 687 fewer deaths due to increased physical activity. Changes in $PM_{2.5}$ and O_3 would result in net health benefits of $4.94 billion/year (95% CI: $0.2 billion, $13.5 billion). Completing 50% of short trips by bicycle would yield $3.8 billion/year in savings (95% CI: $2.7, $5.0 billion), about $1.5 billion less in savings than from reductions in air pollution. We estimate that the combined benefit from improved air quality and physical fitness for the region would exceed $8.7 billion/year, which is equivalent to about 2.5% of the total cost of health care for the five midwestern states in the present study in 2004 (Kaiser Family Foundation 2004).

Of course, an added benefit of removing 20% of VMT from the region is also reduced emissions of greenhouse gases that cause global climate change. The annual reduction would be > 1.8 teragrams carbon dioxide (CO_2) (3.9 billion pounds), using the fleet average passenger car fuel economy of 22.1 mi/gal, with 1 gal gasoline producing 0.882 lb CO_2 (U.S. EPA 2005b).

Few studies have addressed how changes in behavior can affect air quality (Frank and Engelke 2005; Frank et al. 2000), and none have quantified the potential benefits of travel behavior change for pollution control. Comparison with prior BenMAP cost-benefit regulatory analyses suggests that health benefits from reduced air pollution through behavioral changes in personal transportation would be comparable with effects of such top-down measures as the

Clean Air Interstate Rule and the Nonroad Diesel Rule, both air quality regulations having potential for substantial impacts on human health (Hubbell et al. 2009). The magnitude of regional impacts from urban travel mode substitution would be comparable with the annualized benefit of reducing O_3 nationwide to full compliance with the current 75 ppb NAAQS (U.S. EPA 2008).

Compliance with federal air quality standards through conventional measures such as emissions controls entails direct costs to governments and private industry. In contrast, changing personal travel behavior distributes costs and benefits—both financial and otherwise—in a more complex manner, including potentially large personal savings for individuals given the high cost of vehicle ownership and operation. However, in addition to public outreach, education, and incentive programs, drastic decreases in residential VMT would require infrastructure investments to support pedestrian and bicycle traffic, as well as increased public transit. For example, cities would need to designate bicycle lanes on streets, add bicycle lanes or mixed-use nonmotorized paths, and provide additional signage, physical barriers, bicycle traffic signals, and bicycle parking. Infrastructure costs for converting existing roadways to bicycle lanes in the United States range from $2,500 to $50,000/block, depending on the infrastructure needs. In 2010 Portland, Oregon, converted 10 blocks of high-traffic streets to include two-way bike lanes at a cost of $10,000/block, reducing motor vehicle traffic by one lane. In 2011, Chicago added protected bicycle lanes with flexible marker posts and a parking lane for automobiles along four blocks, including a bridge, at a cost of $140,000 (City of Chicago 2011). Increasing this cost estimate to $100,000/block, double the U.S. average cost per mile for bike lane conversion and addition, the $2 billion in health cost savings in the MSA of Chicago alone could retrofit 20,000 blocks (2,500 mi or 4,020 km) with bike lanes. The greater Chicago metropolitan area has > 23,500 mi of urban roads, not including interstate or freeways (Illinois Department of Transportation 2009), so the health care savings could cover the costs of adding bike lanes to every road in 1-10 years.

Although U.S. pedestrians and cyclists may be at higher risk of mortality than their Dutch counterparts (Pucher and Dijkstra 2003), the Dutch results provide a model for safer walking and cycling. Seven of the cities studied here—Chicago, Columbus, Dayton, Indianapolis, Madison, Milwaukee, and Minneapolis/St. Paul—have earned bicycle- friendly rankings from the League of American Bicyclists because they actively support bicycling by providing safe accommodation for cycling and encouraging people to bike (League of American Bicyclists 2010). Thus, some U.S. communities may be more likely than others to exhibit characteristics of Dutch cities that make bicycling feasible. There is already an observed trend of increasing bicycle share across all of the 11 midwestern MSAs, one that is consistent and very large (U.S. Census Bureau 2009). Moreover, there is evidence that U.S. cities with enhanced levels of active transport experience health benefits. Pucher et al. (2010) found that cities with the highest rates of commuting by bicycle or on foot have obesity and diabetes rates 20% and 23% lower, respectively, than cities with the lowest rates of active commuting.

Strengths, limitations, and uncertainties.

Our research, for the first time, has joined models of health effects (BenMAP), census-based vehicle use and emissions (PLUTO), and regional air pollution (CMAQ) to link highly localized changes in travel behavior to regional health outcomes. We also used the newest version of U.S. EPA BenMAP (4.0), which includes baseline incidence rates at the county (versus the regional) level, thus providing greater local specificity than previously possible.

Our results may be a conservative estimate of pollution reductions. We did not evaluate changes in exposure for people who live or work near highways, nor did we assess health effects from decreases in other pollutants (e.g., carbon monoxide, sulfur dioxide) or the synergistic effects of combined changes in O_3 and $PM_{2.5}$. We would expect the reduction in the number of automobiles on the road at any given time to change average speeds and resultant emissions, with variable effects on arterial and local roadways. Comprehensive analysis would require travel-demand modeling (e.g., Bowman and Ben-Akiva 2001) incorporating traveler decision-making, spatially specific changes in roadway and transit networks, demographic information, and employment data to calculate those differences in vehicle activity. Finally, health impacts from changes in long-range transport of O_3 and $PM_{2.5}$ to states downwind of the modeling domain and to neighboring Canadian regions were not analyzed.

Our health benefits analysis also may be conservative because, following current U.S. EPA practice, we used total $PM_{2.5}$ mass and did not differentiate between aerosol species. Recent epidemiological studies suggest that traffic-related emissions may contain more hazardous particulate chemical components. Gent et al. (2009) found more frequent asthma symptoms and inhaler use in children after exposure to $PM_{2.5}$ emissions attributable to motor vehicles compared with emissions from other sources. Bell et al. (2009) found differing associations between cardiovascular and respiratory hospitalization across various chemical species of $PM_{2.5}$. Particles comprising vanadium, nickel, and elemental carbon showed the strongest associations (vanadium and nickel come primarily from transportation emissions).

However, because these epidemiological studies included high diesel truck traffic and its specific emissions profile, these results have slightly less bearing on our analysis of decreases in light- duty automobile emissions.

Our estimates for physical fitness benefits stemming from bicycling 50% of short car trips (≤ 8 km) may underestimate the full benefits of removing these car trips. Not included are the remaining trips that presumably would be achieved by some form of mass transportation or direct walking for very short trips. According to the 2001 National Household Travel Survey, Americans who use mass transit spend a median of 19 min daily walking to and from transit (Besser and Dannenberg 2005). Accounting for fitness benefits from this mode of active transport would involve complex geospatial modeling. Future analyses should consider geo- graphic information system (GIS) technologies in conjunction with energy expenditure measurement tools, such as accelerometers or biometric monitors, to more accurately assess the speed, distance, intensity, and terrain of the cyclist (Bonnel et al. 2009). Finally, for urban planning purposes, assumptions for determining levels of benefits for new bicyclists will stem from city-specific estimates of current bicycling levels and city wide demographics. We used current European bicycling levels to guide our maximum benefit level potentially achievable.

In our study we used chemical transport modeling simulations and empirical CR functions, an experimental framework that adds incremental uncertainty at each step: in the emissions inventory, modeled meteorology, and processes included in the chemical trans- port model. In addition, the ability of the model to reproduce observed ambient surface-level O_3 and $PM_{2.5}$ and their respective sensitivities to emissions changes adds uncertainty.

We used the same suite of response functions and pooling chosen by the U.S. EPA for air pollution rule making; however, the empirical epidemiological CR functions of BenMAP and the choice of valuation estimates are an additional source of uncertainty. The valuation estimates are a function of BenMAP, based on the configuration used by the U.S. EPA. Sensitivity analysis by the California Air Resources Board confirmed that the mean and distribution of premature mortalities from long-term exposure to $PM_{2.5}$ are not sensitive to the random-effects pooling of CR functions (Tran et al. 2009).

We found few outliers among the individual CR calculations that contribute to the reported pooled values. Although we chose to simulate a year (2002) that is representative of the regional climate of the past decade, the magnitude of benefits achieved in any given year depends on interannual variability in meteorology and the resultant ambient air quality.

Conclusion

Our study demonstrates that reduced car travel and enhanced bicycle commuting in urban areas can improve health outcomes within urban, suburban, and even in downwind rural areas. Our results demonstrate that reduced car travel can benefit air quality, human health, and the economy.

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Table 8. Estimated $PM_{2.5}$ reductions, reductions in health impacts, and valuation of reduced $PM_{2.5}$ exposure.

City/data	Mean annual $PM_{2.5}$ reduction[a]	Mortality	Asthma	Chronic bronchitis	Respiratory problems[b]	Cardiovascular problems[c]	Work-loss days[d]	Total savings
Chicago								
Incidence	0.05 (0.02, 0.15)	162 (63, 260)	802 (91, 2,301)	29 (5, 53)	36,690 (30,233, 43,145)	253 (99, 407)	5,923 (5,161, 6,685)	
Savings		1,273 (176, 3,361)	0.04 (0.01, 0.13)	13 (1, 44)	2.47 (1.44, 3.61)	16.7 (5, 40.9)	1 (0.96, 1.2)	1,305 (184, 3,449)
Cincinnati								
Incidence	0.03 (0.01, 0.10)	26 (10, 42)	100 (11, 288)	4 (0.7, 7)	4,751 (3,918, 5,583)	34 (13, 54)	763 (665, 861)	
Savings		212 (29, 549)	0.005 (0.001, 0.02)	1.6 (0.14, 6)	0.32 (0.18, 0.46)	2.27 (0.68, 5.6)	0.13 (0.11, 0.15)	212 (30, 561)
Cleveland								
Incidence	0.05 (0.02, 0.16)	53 (21, 85)	184 (21, 527)	7 (1, 13)	8,804 (7,264, 10,345)	74 (28.5, 119)	1,405 (1,224, 1,586)	
Savings		418 (58, 1,105)	0.01 (0.001, 0.03)	3 (0.3, 11)	0.60 (0.35, 0.88)	4.86 (1.4, 11.9)	0.23 (0.2, 0.27)	427 (60, 1,129)
Columbus								
Incidence	0.04 (0.02, 0.14)	27 (11, 43)	124 (14, 355)	4 (1, 8)	5,854 (4,829, 6,879)	35 (13.5, 55.9)	951 (828, 1,073)	
Savings		212 (29, 561)	0.007 (0.001, 0.02)	1.9 (0.2, 6.7)	0.39 (0.23, 0.57)	2.37 (0.71, 5.8)	0.16 (0.14, 0.18)	217 (31, 574)
Dayton								
Incidence	0.04 (0.03, 0.10)	14 (6, 23)	47 (5, 136)	2 (0.4, 3.4)	2,278 (1,880, 2,676)	18 (7, 29)	365 (318, 412)	
Savings		112 (15, 296)	0.003 (0, 0.008)	0.8 (0.07, 2.8)	0.15 (0.09, 0.22)	1.22 (0.36, 3)	0.06 (0.05, 0.07)	114 (16, 302)
Detroit								
Incidence	0.05 (0.02, 0.16)	106 (41, 171)	462 (52, 1,325)	17 (3, 31)	21,181 (17,462, 24,899)	158 (61.5, 254)	3,395 (2,958, 3,832)	
Savings		836 (115, 2,208)	0.023 (0.003, 0.08)	7.3 (0.6, 26)	1.4 (0.83, 2.09)	10.46 (0.26, 2.2)	0.66 (0.58, 0.75)	856 (120, 2,262)
Grand Rapids								
Incidence	0.03 (0.02, 0.06)	7 (3, 11)	45 (5, 130)	2 (0.3, 2.9)	2,023 (1,667, 2,379)	13 (4.75, 20.3)	327 (285, 369)	
Savings		54 (7, 143)	0.002 (0, 0.007)	0.66 (0.06, 2.3)	0.13 (0.08, 0.19)	0.88 (0.26, 2.2)	0.054 (0.047, 0.061)	56 (8, 148)
Indianapolis								
Incidence	0.03 (0.01, 0.09)	19 (7, 30)	85 (10, 243)	3 (0.5, 5.2)	3,676 (3,024, 4,328)	24 (9.3, 38.8)	592 (516, 669)	
Savings		146 (20, 386)	0.005 (0.001, 0.01)	1.2 (0.11, 4.3)	0.25 (0.14, 0.36)	1.59 (0.48, 3.9)	0.1 (0.09, 0.12)	149 (21, 394)
Madison								
Incidence	0.02 (0.02, 0.04)	1 (0.44, 1.8)	10 (1, 28)	0.42 (0.08, 0.8)	565 (469, 661)	3 (1.2, 5)	93 (81, 105)	
Savings		8.8 (1.2, 23.3)	0.001 (0, 0.002)	0.18 (0.02, 0.6)	0.037 (0.022, 0.053)	0.23 (0.067, 0.55)	0.016 (0.014, 0.018)	9 (1, 24)
Milwaukee								
Incidence	0.04 (0.02, 0.08)	12 (5, 19)	73 (8, 210)	3 (0.5, 5)	3,407 (2,809, 4,005)	21 (7.7, 34.3)	545 (475, 616)	
Savings		93 (13, 246)	0.004 (0, 0.01)	1.18 (0.10, 4.2)	0.22 (0.13, 0.33)	1.72 (0.51, 4.23)	0.095 (0.08, 0.1)	96 (14, 254)
Twin Cities								
Incidence	0.01 (0.00, 0.06)	7 (2.7, 11)	87 (10, 248)	3 (0.65, 6)	4,379 (3,619, 5,139)	27 (10, 44)	709 (618, 800)	
Savings		54 (7, 142)	0.005 (0.001, 0.01)	1.46 (0.13, 5.2)	0.28 (0.17, 0.42)	1.95 (0.58, 4.8)	0.13 (0.11, 0.15)	57 (8, 152)
Total MSAs								
Incidence	0.01 (0.00, 0.16)	433 (169, 698)	2,018 (228, 5,790)	75 (14, 137)	93,607 (77,175, 110,037)	659 (255, 1,062)	15,067 (13,128, 17,006)	
Savings		3,484 (480, 9,199)	0.11 (0.01, 333)	32 (2.8, 112)	6.16 (3.59, 9.01)	43.4 (13, 106.3)	2.6 (2.38, 3.1)	3,570 (501, 9,875)
Outside MSAs total								
Incidence	92 (35, 149)	541 (60.9, 1,552)	21.64 (3, 40.2)	579 (278, 878)	200.6 (71.8, 332)	4,280 (3,729, 4,830)		
Savings		726.7 (100, 1,919)	0.023 (0.003, 0.07)	7.35 (0.640, 26)	1.36 (0.792, 1.99)	11.1 (3.27, 27.4)	0.489 (0.426, 0.552)	747.02 (105, 1,975)
Region total								
Incidence	525 (204, 806)	2,559 (289, 7,342)	97 (17, 177)	94,186 (77,453, 110,915)	860 (327, 1,394)	19,347 (16,857, 21,837)		
Savings		4,143 (571, 10,937)	0.13 (0.02, 0.4)	39.1 (3.4, 138)	7.52 (4.38, 10.99)	54.5 (16.2, 132)	3.24 (2.82, 3.65)	4,247.5 (598, 11,222)

Values for incidence represent estimated incidence per adverse health effect avoided due to a change in air pollution in the given city per year; savings are presented in millions of dollars. Values in parentheses are 95% confidence intervals, and all changes are annualized.

[a]Change in PM 2.5 (μg/m) was calculated as area averaged and reported with a range of minimum and maximum grid cell values; data for $PM_{2.5}$-related health effects estimated in this analysis (and the source of the PM concentration-response functions used to estimate the change in incidence) are from Abbey et al. (1995), Dockery et al. (1996), Ito (2003), Laden et al. (2006), Moolgavkar (2000a, 2003), Norris et al (1999), Ostro (1987), Ostro and Rothschild (1989), Ostro et al. (2001), Peters et al. (2001), Pope et al. (1991, 2002), Schwartz and Neas (2000), Sheppard (2003), and Vedal et al. (1998). [b]Respiratory problems include upper and lower respiratory symptoms, hospital admissions (respiratory), emergency room visits (respiratory), and cases of acute bronchitis. [c]Cardiovascular problems include nonfatal acute myocardial infarctions and cardiovascular hospitalizations. [d]Yearly work-loss-day incidence based on estimates from the 1996 National Health Interview Survey (Adams et al. 1999).

Table 9. Estimated O3 changes, changes in health impacts, and valuation of changes in O3 exposure.

City/data	Changes in O_3 (ppm)[a]	Acute Resp. Symptoms	ER visits (respiratory)	HA (respiratory)	Mortality	School-loss days	Worker Productivity	Total savings
Chicago								
Incidence	-0.09 (-0.23, 0.39)	-5,780 (-10,131, -1,431)	-3 (-12, 2.4)	-8 (-18. 0.87)	-14 (-22, -6)	-1,762 (-3,174, -351)	-13,564	
Savings		-0.365 (-0.718, 0.047)	-0.001 (-0.004, 0.001)	-0.19 (-0.41, 0.03)	-108 (-305, 38)	-0.17 (-0.3, -0.03)	-0.017	-109 (-306, 37)
Cincinnati								
Incidence	-0.13 (-0.25, 0.21)	483 (-229, 1,194)	0.08 (-1.1, 1.3)	0.53 (-0.72, 1.76)	0.78	151 (-75, 377)	1,279	
Savings		0.03 (-0.02, 0.09)	0 (0, 0)	0.011 (-0.02, 0.04)	6.2 (-20.2, 37.3)	0.014 (-0.007, 0.036)	0.002	6.2 (-20.2, 37.5)
Cleveland								
Incidence	-0.17 (-0.33, 0.70)	353 (-871, 1577)	-0.15 (-2.6, 2.2)	0.35 (-2.2, 2.8)	0.54 (-2.3, 3.4)	106 (-271, 483)	2,490	
Savings		0.022 (-0.07, 0.12)	0 (-0.001, 0.001)	0.008 (-0.05, 0.06)	4.4 (-47.4, 61)	0.01 (-0.03, 0.05)	0.003	4.412 (-47.5, 61.3)
Columbus								
Incidence	-0.2 (-0.27, 0.23)	199 (-555, 953)	-0.07 (-1.3, 1.09)	0.19 (-0.9, 1.3)	0.45 (-0.85, 1.8)	58 (-182, 297)	1,697	
Savings		0.013 (-0.04, 0.07)	0 (0, 0)	0.005 (-0.02, 0.03)	3.64 (-20, 29.7)	0.005 (-0.017, 0.028)	0.002	3.669 (-20, 29.9)
Dayton								
Incidence	-0.21 (-0.26, 0.01)	713 (362, 1,064)	0.48 (0, 1.4)	0.99 (0.26, 1.8)	2 (1.3, 2.9)	209 (100, 318	2,568	
Savings		0.045 (0.02, 0.08)	0 (0, 0.001)	0.02 (0.004, 0.038)	16 (2.5, 40.6)	0.02 (0.01, 0.03)	0.003	16.462 (2.6, 40.7)
Detroit								
Incidence	-0.17 (-0.29, 0.18)	830 (-976, 2,634)	0.46 (-1.7, 3)	0.58 (-2.3, 3.3)	1 (-2.5, 4.7)	257 (-326, 840)	1,389	
Savings		0.052 (-0.07, 0.19)	0 (-0.001, 0.001)	0.011 (-0.05, 0.07)	8.5 (-48, 68)	0.024 (-0.031, 0.08)	0.002	8.631 (-48.5, 68.7)
Grand Rapids								
Incidence	-0.23 (-0.29, 0.07)	1,124 (571, 1,677)	0.65 (0, 1.9)	1 (0.34, 1.8)	2 (1.5, 3.4)	363 (174, 552)	12,235	
Savings		0.071 (0.033, 0.12)	0 (0, 0)	0.02 (0.005, 0.035)	19.3 (3, 48)	0.035 (0.02, 0.05)	0.015	19 (3, 48)
Indianapolis								
Incidence	-0.15 (-0.22, 0.12)	532 (13, 1,051)	0.32 (-0.39, 1.3)	0.72 (-0.38, 1.8)	1 (0.23, 2.1)	169 (-9.2, 347)	2,036	
Savings		0.034 (-0.002, 0.076)	0 (0, 0)	0.017 (-0.009, 0.04)	9.4 (-8, 33)	0.016 (-0.001, 0.033)	0.003	9.476 (-8, 33)
Madison								
Incidence	-0.12 (-0.16, 0.04)	135 (33, 237)	0.03 (-0.01, 0.11)	0.11 (0.02, 0.21)	0.25 (0.12, 0.39)	41 (12, 70)	436	
Savings		0.009 (0.002, 0.017)	0 (0, 0)	0.002 (0, 0.004)	1.99 (0.28, 5.2)	0.004 (0.001, 0.007)	0.001	2.002 (0.28, 5.2)
Milwaukee								
Incidence	-0.12 (-0.20, 0.14)	134 (-292, 559)	-0.09 (-0.74, 0.45)	0 (-0.61, 0.57)	0.2 (-0.6, 1.1)	21 (-116, 158)	-60	
Savings		0.008 (-0.02, 0.04)	0 (0, 0)	0.001 (-0.01, 0.01)	1.65 (-11.5, 16.9)	0.002 (-0.01, 0.02)	0	1.66 (-11.6, 16.9)
Twin Cities								
Incidence	-0.05 (-0.11, 0.38)	-2,190 (-3,590, -790)	-0.76 (-2.5, 0.24)	-2 (-3.7, -0.3)	-4 (-6.5, -2.3)	-588 (-994, -181)	-7,881	
Savings		-0.138 (-0.25, -0.039)	0 (-0.001, 0)	-0.039 (-0.07, -0.003)	-34.7 (-88.9, 2.57	-0. 056 (-0.095, -0.002)	-0.01	-34.9 (-89.3, 2.5)
Total MSAs								
Incidence	-0.07 (-0.33, 0.70)	-3,467 (-15,663, 8,723)	-963 (-8,281, 5,764)	-5.97 (-28, 16)	-9 (-32, 14)	-976 (-4,860, 2,909)	2,627	
Savings		-0.22 (-1.15, 0.72)	-0.001 (-0.008, 0.006)	-0.134 (-0.63, 0.36)	-71.7 (-543, 380)	-0.093 (-0.46, 0.28)	0.00330	-72.14 (-545.38, 381.47)
Outside MSAs total								
Incidence		33,628 (17,087, 50,167)	17 (0, 51.5)	47 (10.9, 83)	91 (53.3, 129.6)	9,608 (4,610, 14,606)	282,669	
Savings		212 (0.995, 3.6)	0.0073 (0, 0.019)	1.01 (0.222, 1.81)	763.2 (118, 1,1893)	0.914 (0.439, 1.39)	0.353	767.6 (120, 1,900)
Region total								

Incidence	30,161 (1,423, 58,891)	14.63 (-22.4, 66.8)	41.13 (-17.2, 98.8)	82.6 (21.3, 143.3)	8,632 (-250.2, 17,515)	285,296	
Savings	1.91 (-0.14, 4.33)	0.006 (-0.008, 0.03)	0.876 (-0.42, 2.17)	691.5 (-425, 2,273)	0.822 (-0.0239, 1.67)	0.357	695.5 (-425, 2,281)

Notes for Table 9: Values for incidence represent estimated incidence per adverse health effect avoided due to a change in air pollution in the given city per year; costs are expressed as negative and benefits as positive (millions of dollars). Values in parentheses for incidence and savings are 95% confidence intervals (in most cases rounded to nearest decimal), and all changes are annualized. [a]Change in O_3 season average daily maximum 8-hr are calculated as mean area (range of grid cell values). Data for O_3 -related health effects (and the source of the O concentration-response functions used to estimate the change in incidence) estimated in this analysis are from Bell et al. (2004, 2005), Burnett et al. (2001), Chen et al. (2000), Crocker et al. (1981), Gilliland et al. (2001), Huang et al. (2005), Ito et al. (2005), Jaffe et al. (2003), Levy et al. (2005), Moolgavkar et al. (1997), Ostro and Rothschild (1989), Peel et al. (2005), Schwartz (1994a, 994b,1995, 2005), and Wilson et al. (2005).

Table 10. Results of HEAT analysis assuming that 50% of short trips are completed by bicycle.

MSA	No. of trips by bicycle (millions)	No. of trips/day (millions)	Average distance (km)	Maximum annual benefit (millions of $)[a]	Savings/ individual cyclist/year ($)	Savings per trip ($)	Mean annual benefit (millions of $)	No. of people to benefit	Lives saved
Suburban									
Chicago	280.77	0.77	3.65	972	2,298	10.19	724	211,566	131
Cincinnati	53.15	0.15	3.55	179	2,235	9.91	133	40,047	24
Cleveland	93.02	0.26	3.55	313	2,235	9.91	233	70,083	42
Columbus	51.19	0.14	3.55	172	2,235	9.91	128	38,567	23
Dayton	33.09	0.09	3.55	111	2,235	9.91	83	24,935	15
Detroit	197.11	0.54	3.55	664	2,235	9.91	495	148,506	90
Grand Rapids	35.14	0.10	3.98	133	2,506	11.11	99	26,474	18
Indianapolis	57.46	0.16	3.98	217	2,506	11.11	162	43,294	29
Madison	25.23	0.07	3.64	87	2,291	10.16	65	19,010	12
Milwaukee	50.85	0.14	3.64	176	2,291	10.16	131	38,314	24
Twin Cities	109.30	0.30	3.58	371	2,253	10	277	82,346	50
Total Suburban	986.31	2.70	3.66	3,396	2,302	10.21	2,530	743,142	459
Urban									
Chicago	197.16	0.54	3.43	652	2,160	9.58	4,859	151,022	88
Cincinnati	29.03	0.08	3.34	92	2,103	9.33	685	21,870	12
Cleveland	49.56	0.14	3.34	157	2,103	9.33	1,170	37,338	21
Columbus	33.45	0.09	3.34	106	2,103	9.33	790	25,205	14
Dayton	10.08	0.03	3.34	34	2,103	9.33	252	7,597	5
Detroit	62.70	0.17	3.54	211	2,228	9.89	1,569	47,238	28
Grand Rapids	10.64	0.03	3.54	36	2,228	9.89	266	8,013	5
Indianapolis	21.21	0.06	4.47	90	2,815	12.48	670	15,982	12
Madison	NA	NA	3.79	NA	NA	NA	NA	NA	NA
Milwaukee	30.80	0.08	3.79	111	2,386	10.58	83	23,208	15
Twin Cities	58.97	0.16	3.5	196	2,203	9.77	146	44,430	26
Total Urban	503.60	1.38	3.58	1,684	2,039	9.05	1,255	381,902	228
Grand Total	1489.92	4.08	3.62	5,080	2,171	9.63	3,784	112,5045	687

NA, not applicable.
[a]The maximum annual benefit is the total value of reduced mortality based on the level of cycling entered by the user.

Figure 5

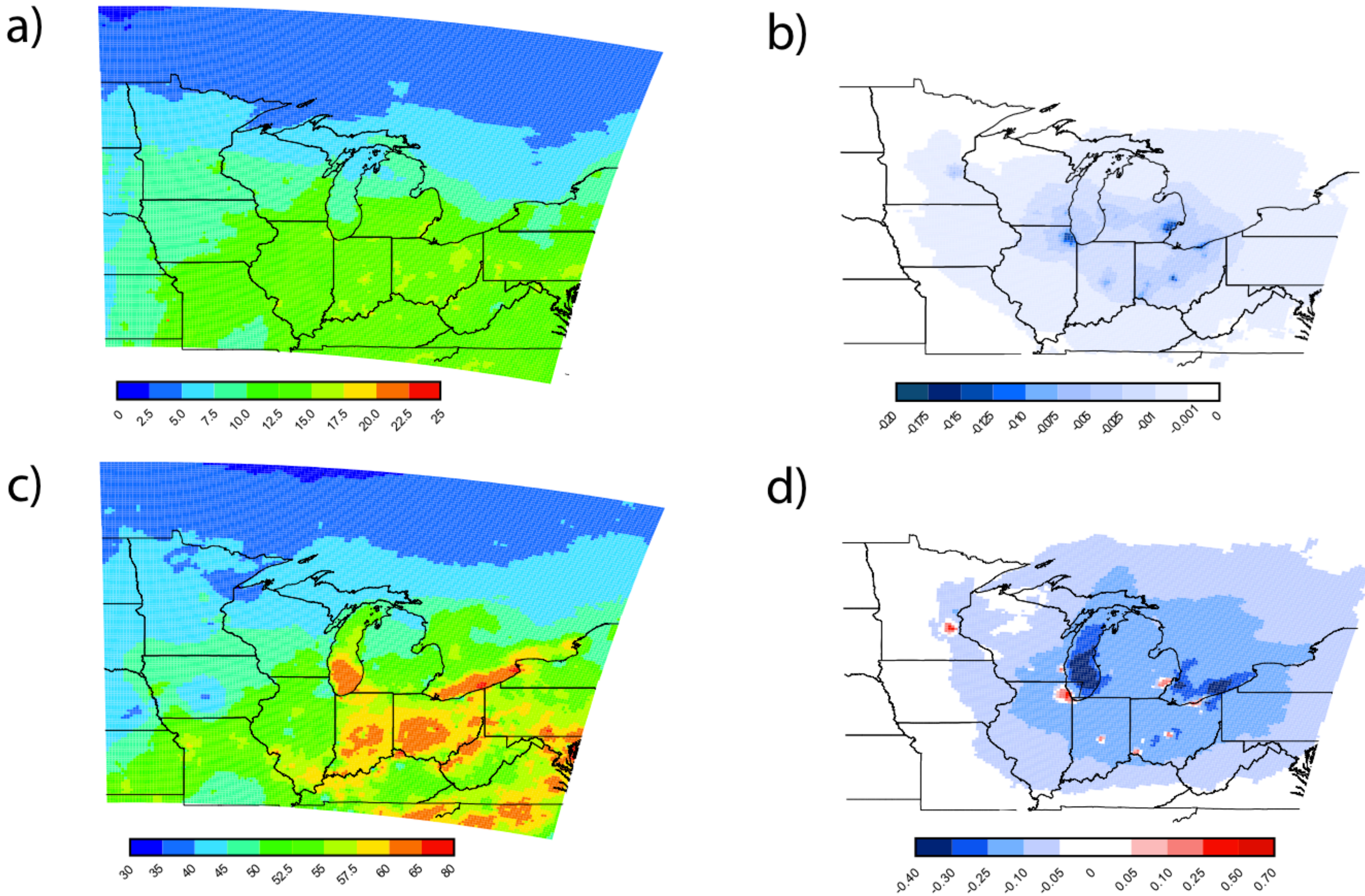

Figure 5: Results of air quality analysis for $PM_{2.5}$ (A,B) and O_3 (C,D) by location. (A) 2002 annual average $PM_{2.5}$ concentration ($\mu g/m^3$). (B) Estimated reduction in 2002 annual average $PM_{2.5}$ concentration ($\mu g/m^3$) due to changes in urban and suburban mobile emissions. (C) 2002 average daily 8-hr maximum O_3 concentration (ppb) for the O_3 season (1 May–30 September). (D) Estimated change in 2002 average daily 8-hr maximum O_3 concentration (ppb) for the O_3 season due to changes in urban and suburban mobile emissions. Data were generated in BenMAP 4.0 and mapped in ArcGIS 10 (ESRI, St. Paul, MN).

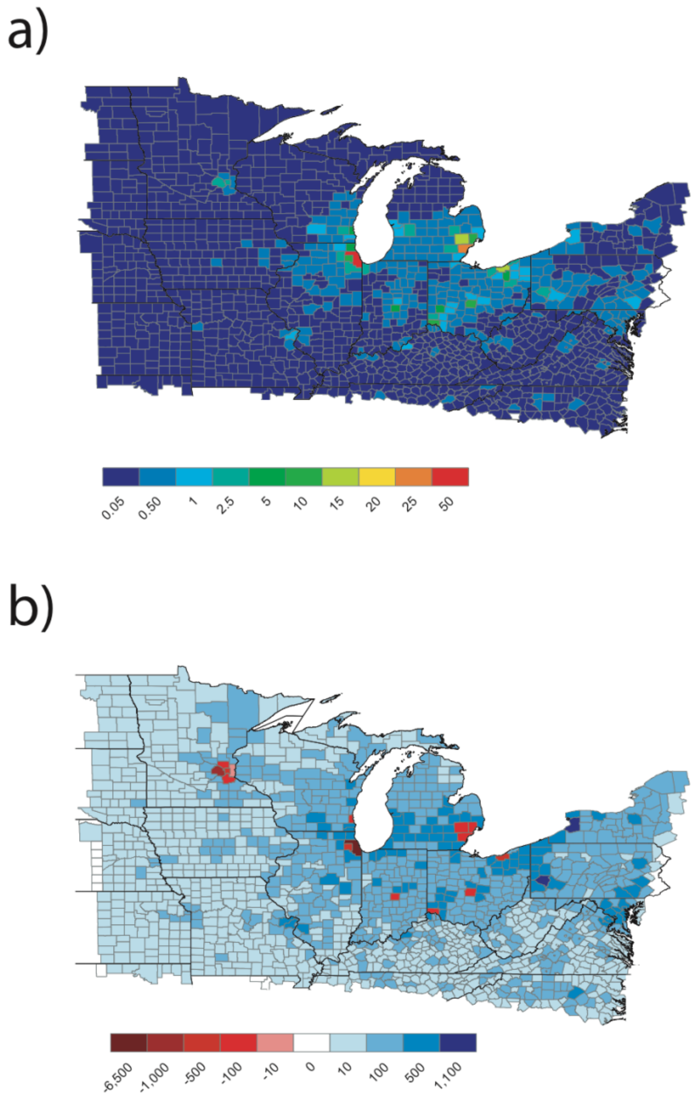

Figure 6

Examples of altered incidence of negative health outcomes by county. (A) Annual reduction in premature mortalities due to reduced $PM_{2.5}$; units reflect the reduction in number of deaths per year. (B) Annual reduction in cases of acute respiratory symptoms due to changes in O_3; units reflect the number of cases of acute respiratory symptoms per year. Data were generated in BenMAP 4.0 and mapped in ArcGIS 10.

Chapter 5

Conclusions

Overview and Summary of Results

My bicycle commute to work is not very treacherous. I pass through a quaint neighborhood, cross a couple busy streets, wait at two stoplights, and I arrive at my destination in a mere 1.2 miles. However, such ease of bicycling is not the case for others, which is why they often resort to driving. Many people travel by private automobile because they have no practical transportation alternative. There are many communities in the United States that are supportive of active transportation; however, many are not. The goal of this dissertation was to provide evidence for transforming communities so that people have the option to bicycle, walk, or take public transit to their respective destinations. My results in this dissertation scientifically document an understanding of the associations between the built environment and active transportation behavior and of the co-benefits of active transportation. Below I summarize the main conclusions and the contributions of each chapter to this interdisciplinary field of active living research.

In the second chapter, I highlight that people will be more likely to conduct active transport if they live in areas with more non-residential destinations; have access to more bikeable and walkable streets; and generally perceive their community to have many destinations within close proximity. I confirm the notion that the presence of built environment supports of active transportation are independent of perceptions of the built environment. This further supports a “build it and they will come” approach to bicycle and pedestrian infrastructure planning, and may be a successful local approach for communities. Thus, there are features of the built environment that we can change to improve people's active transportation levels. This suggests that policies that facilitate active transportation within the built environment should be implemented by providing or improving bicycling and walking infrastructure and by integrating mixed land-use/smart growth principals into common practice.

In the third chapter, I focus solely on objective measures of the built environment and their relationship to active transportation. I compare my active transportation index — which includes proximity and connectivity measures and an emphasis on built environment features that foster active transportation — to walkscore.com, which includes only proximity measures. I establish that both proximity and connectivity need to be considered when making decisions about urban planning and design. Similar to the previous chapter, my findings support policy initiatives that support multi-use zoning to increase accessibility of residential and non-residential destinations alongside those initiatives that support accessibility for all modes of transportation, motorized and non-motorized.

In the last chapter, alongside my colleagues, I combined data on transportation, automotive emissions, and health effects of exposure to air pollution to estimate how switching to bicycling could impact air quality, health, and associated costs. Replacing all short auto trips with active transport and public transportation, and replacing half of them with bicycle trips during the warmer half of the year would yield major economic and health benefits: for the 11 largest cities in the Upper Midwest, 1,300 premature deaths/year, $8 billion/year. And though the reduced car travel and enhanced bicycle commuting occurred in urban areas, we projected improved health outcomes within urban, suburban, and even in downwind rural areas. This is the first time anyone has used state-of-the-science computer models to assess the health benefits of behavioral changes in the exact same way as EPA tests proposed federal air pollution regulations, and found that the results are comparable. This study highlights the many co-benefits from implementing this behavior change – improving human health from increased physical activity and reduced air pollution, reduced fossil fuel burning and source of GHGs and subsequent climate change, and reduced health care costs. This study presents a "golden opportunity" -- promoting bicycling as a cost-effective investment with tremendous, multiple returns.

Reflections and Recommendations for Future Research

Research in this area of the built environment and physical activity began only at the beginning of the 21st Century, so there are still gaps that need to be filled. As research continues, I encourage the use of ecological models of health promotion to bring policy and environmental determinants of healthy behavior and health behavior change into sharper focus. Ecological models will draw out the synergies between environmental and policy influences as we continue to understand the complexities of the relationships between the different physical activity behavior domains.

As research moves forward, it is also important to acknowledge the potential benefits of collaborations among researchers in diverse fields (e.g., behavioral science, public health, transportation, urban planning, parks and recreations, architecture, community and landscape architecture, and social marketing). Since the 2000's, we have seen the beneficial collaboration of transportation planners and physical activity researchers (Sallis et al. 2004). As evidence shows that land-use and transportation decisions affect physical activity, it is even more important that the transportation field prioritizes physical activity for both practice and research. Likewise, transportation and land-use policies should appear on the public health agenda as well.

Future research should also focus on determining the optimal methods for collecting self-reported data on physical activity. In my dissertation, we utilized self-reported physical activity for several of the domains. However, we recognize the potential for bias. Further studies should be conducted using accelerometers to objectively record active transportation behavior rather than solely relying on self-reported physical activity information.

Focus should also be given to the promise of GIS data, and its triangulation with health and other observational data. Using GIS-derived data may potentially improve measurement abilities and reduce the time-consumptiveness of observational studies.

Priority also needs to be given to designing longitudinal studies that account for the temporal issues between exposure to the environment and behavior change. My dissertation is one example of many cross-sectional studies. Longitudinal studies must be designed in order to infer causality between built environment features and physical activity behaviors.

We also need to be answering questions about how the built environment affects populations differently. For example, does the built environment have similar effects on active transportation among the majority population, among diverse racial/ethnic, low SES, and various age and ability groups? And what about people living in urban, suburban, and rural areas? It is important to recognize the environmental injustices and health disparities that fall upon those people living in low income and minority neighborhoods. This is another area where fields of transportation, urban and regional planning, and public health through collaboration can guide changes in zoning codes and transportation policies to reduce population disparities in physical activity.

Support for Policies Encouraging Active Transport

We know that walking and cycling rates are higher in cities and countries where policies are put in place to encourage those behaviors (Pucher et al. 2010). However, we have also seen the success of policies or interventions that promote travel without specifically targeting walking and cycling – rather, they may discourage auto travel by promoting alternatives. For example, cycling levels in London doubled following the introduction of a congestion charge alongside significant investment in cycling infrastructure (de Nazelle et al. 2011). Introducing comprehensive promotion programs including constructing bicycle facilities and bike sharing systems in cities such as Berlin, Paris, Barcelona, and Bogota resulted in bike share of trips more than doubling (Pucher et al. 2010).

Key Policy Recommendations

1. Maintain the integrity of the Transportation Enhancements, Safe Routes to School programs, and recreational trails programs, which are all currently in jeopardy of being eliminated. Last year there were over 3,000 of these programs offered, and in 2009 more than four billion record-breaking bicycle trips were taken in the United States. We simply have no grounds to remove these programs, which make active transportation a safe option for people of all ages.

2. Incentivize coordination of land use and transportation planning through Smart Growth Principals and Initiatives. We also need to enhance the viability of multi-modal transportation. One solution is rewarding jurisdictions that adopt land use policies promoting greater densities and mixed land use with funding for additional bicycle and pedestrian projects.
3. Enact policies, such as Complete Streets, that compel state, regional, and local governments to improve conditions for non-motorized modes of transport. Too often roads are built without consideration for those who do not own cars. A federal complete streets policy would require that the needs of bicyclists and pedestrians be considered in all federally-funded transportation projects.

Thus, transportation policy has enormous potential to catalyze the development of healthy communities, but it requires an initial investment and a long-term commitment. This is not a huge paradigm shift. Instead, I am promoting active transportation as a cost-effective investment with tremendous, multiple returns. The goal, then, is to improve transportation for everyone while delivering multiple important benefits, including better respiratory and cardiovascular health; improved physical fitness; less emotional stress; cleaner air; quieter streets; fewer traffic injuries and deaths; sustained mitigation of the threat of global climate change; and greater access to jobs, nutritious foods, and other essentials.

Findings from my dissertation can help decision-makers to make more informed urban policy choices. And these choices, whether big or small, can make our communities more healthy and sustainable in every way. Our transportation policy represents one of the largest, most fundamental public health opportunities facing our nation. Through policies that support active transportation, I hope we can achieve 'sustainable health' through taking care of current populations without compromising the opportunity for health of further generations.

References

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APPENDIX

Appendix A WASABE Instrument

(WASABE)
Wisconsin Assessment of the Social and Built Environment
Survey of the Health Of Wisconsin

Date:	
Day of Week:	
Start Time:	**Stop Time:**
Data Collected by (check all that apply): __Foot __Auto	
Assessor ID: **Initials:**	**Topography:** ☐ Mostly Flat ☐ Moderately Hilly ☐ Mostly Hilly
Classification: ☐ Urban ☐ Suburban ☐ Rural	
Household ID:	**Block Group:**
Polygon ID:	
Segment ID:	**Segment length:** (only if it is a street network terminal)
Intersection(s) ID: (only if it needs to be observed - use page 4)	

Weather Conditions:
Temperature (check one):
___very cold (below 20°F)
___cold (20-39°F)
___cool (40-54°F)
___mild (55-69°F)
___warm (70-84°F)
___hot (85-95°F)
___very hot (over 95°F)
Temp. (& wind speed if applicable) check one:
___were based on an official source
___were estimated by observer
Weather Description (check all that apply):
___sunny to partly cloudy
___mostly cloudy to cloudy
___light to moderate rain
___heavy rain or thunderstorm
___light to moderate snow or freezing rain
___moderate to heavy snow, freezing rain
___heavy fog
___snow on the ground
___ice on the ground
___strong winds (approx. 25 mph or higher)

1.
2. What **types** of residential buildings are present in the segment?

Residential Buildings	Yes	No
a. Single family homes		
b. Multi-unit homes (2-6 units)		
c. Apartment building/complex or condominium (>6 units)		
d. Apartment over retail in multi-story building		
e. Mobile home or trailer (do not count if part of a trailer park)		
f. Mobile home or trailer park/community		
g. Other (Specify):		

3. How many of each type of non-residential building are present in the segment?
If present, how many are adjacent to the sidewalk (# Adj to SW)?

Non-Residential Businesses (1/3)	#	# Adj to SW
a. Bars/nightclubs		
b. Liquor/tobacco stores		
c. Wine stores		
d. Fast food restaurants (i.e., you order and you bring your food to your table)		
e. Other restaurants (i.e., sit-down restaurants; you order & wait staff brings your food to table)		
f. Coffee Shops (e.g., Ancora, Alterra, or local)		
g. Specialty/Ethnic Food Store		
h. Food supermarkets or grocery stores		

Non-Residential Buildings or Businesses (2/3)	#	# Adj to SW
i. Convenience stores or gas station stores		
j. Gas Station		
k. Pharmacies, drug stores (primarily non-food; e.g. Walgreens, locally owned pharmacies, etc.)		
l. Health care facilities (e.g., hospital, elderly residence, clinic, dentist, acupuncturist, etc.)		
m. Retail stores (e.g., video rental, florist, bookstore, clothing, sporting goods, etc.)		
n. Indoor malls, super centers, department stores, “big box” stores (e.g., Walmart, Home Depot, etc.)		
o. Service providers (e.g., hair salon, bank, laundromat, dry cleaners, accountant, car wash, car repair, post office, FedEx, etc.)		
p. Indoor Fitness facilities (e.g., gyms, fitness centers, health clubs, yoga, martial arts, or dance studios, etc.		
q. Cultural entertainment (e.g., movie theaters, museum, library, etc.)		
r. Other entertainment (e.g., bowling alley, karaoke, billiards, etc.)		

s. Non-religious community center (e.g., senior center, neighborhood center, drop-in center, etc.)		
t. Church, synagogue, mosque, other religious center		
u. Educational facilities (e.g., university, tech school, K-12 schools, daycare, ESL facility, etc.)		
v. Government facilities (e.g. police, courthouse, etc.)		
Non-Residential Buildings / Businesses (3/3)	**#**	**# Adj to SW**
w. Transportation facilities (e.g. train or bus station)		
x. Hotels, motels, inns, etc.		
y. Office space		
z. Warehouse, storage facilities, factory, industrial building, etc.		
aa. Farm Complexes (Barn, silo, rural storage facility, etc.)		
bb. Other non-residential (Specify type): ______________________		

Addendum: Building size:

Tallest building in the segment. ☐ **Res.** ☐ **Non-Res.** ☐ **Mixed Use**

How many stories tall is (are) the tallest building(s)? ______________

4. What types of recreational facilities are visible in the segment?

Recreational Facilities	Yes	No
a. Indoor fitness facilities (e.g., gyms, fitness centers, health clubs, yoga, martial arts, or dance studios, etc.)		
b. Sports/playing field, courts, or track		
c. Playground or splash pad		
d. Golf course		
e. Pool (indoor or outdoor)		
f. Off-road walking/biking trail or path		
i. On one side of the road		
ii. On both sides of the road		
iii. Crossing the road		
g. Other Recreational Facilities (Specify Type): ______________________		

5. What is the predominant land use? Check one or two that apply.

Predominant Land Use	Check 1 or 2
a. Residential buildings/yards	
b. Commercial buildings / businesses	
c. Public government buildings	
d. Manufacturing	
e. School/school yards	
f. Parking lots or garages	
g. Park or designated green space	
h. Abandoned buildings	
i. Undeveloped land/farmlands/woodlands	
j. Other (Specify): ______________________	

6. Evaluate the traffic volume and type.

Traffic Volume

a. What is the speed limit in the segment?

Enter MPH: ___________ check if unknown: ☐

b. Scan the entire segment and count any cars, trucks, and other motorized vehicles driving within the segment during 2 minutes. Check the appropriate box for number of vehicles.

☐ **0** ☐ **1-4** ☐ **5-15** ☐ **16-34** ☐ **35+**

check if NA: ☐ If NA, give reason: ________________

c. Bus or other public transportation present

Yes ☐ **No** ☐

7. On what type of street is the segment? Check **ONE** best description.

Check 1	Street Type
☐	Pedestrian only / Closed to motorized traffic
☐	Pedestrian with limited access to certain motorized vehicles (e.g., buses, delivery trucks, etc.)
☐	Dead end street (either one way or two way)
☐	One way street
☐	Two way street
☐	Other (Specify): ______________________

8. Describe the following **STREET** characteristics **<u>in the segment ONLY</u>** (**not including intersections**)

Street Characteristics	Enter #	
a. Traffic lanes (within the segment)		
b. How many pedestrian crosswalks are present? (within the segment)		
i. How many pedestrian crosswalks have missing pieces or sections worn off? (within the segment)		
c. Walk/Don't Walk signals (within the segment)		
d. Ramps or Curb Cuts (within the segment)		
	Yes	**No**
e. Pedestrian safety signs and devices (within the segment)		
f. Medians or pedestrian islands (within the segment)		

i. Pedestrian Pushbutton on Median		
g. Traffic calming devices (within the segment)		
h. On-street parking available (within the segment)		
i. With Bulb-Out		
ii. Without Bulb-Out		
i. Railroad (within the segment)		

9. Please answer the following questions regarding **bicycling** conditions and follow the skip patterns

Bicycle Transportation/Commuting			
On-Road Biking Conditions	**Yes, both sides**	**Yes, one side**	**No**
a. Is there an on-street, paved, marked bike lane?			
i. If **Yes [for Q.8(a.)]:** Are there any obstructions in the marked bike lane (e.g., drainage gates, parked cars, etc.)? **Continue on to Q.8(a.)(ii.)**			
ii. If **Yes [for Q.8(a.)]:** Are there any parts of the bike lanes that are missing or worn off? **If Yes: Skip to Q.9**			
iii. If **No [for Q.8(a.)]:** Is the outermost lane wide enough (~15 ft.) that it would reasonably fit a motorized vehicle and a cyclist side by side? **If No: Skip to Q.9**			
iv. If **Yes [for Q.8(a.)(iii.)]:** Are there obstructions in the outermost part of the lane (e.g., drainage gates, parked cars, etc.)?			

10. Are sidewalks present in the segment?
Choose **one** description below that is the best fit.

Sidewalk Analysis
☐ Sidewalk is present in the entire segment
☐ Sidewalk is present, but missing some parts in the segment
☐ Sidewalk is completely or mostly missing (**Skip to Q.10**)

Sidewalk Features	**Yes > 1/2**	**Yes ≤ 1/2**	**No**
a. Grassy or other buffer area between street/curb and sidewalk			
b. Major misalignments or cracks in the sidewalk			

11. Does the street segment have the following characteristics?

Neighborhood Characteristics (1/2)	**Yes > 1/2**	**Yes ≤ 1/2**	**No**	**NA**
a. Do the buildings have a variety of building materials and/or a variety of color?				
b. Are there buildings in poor condition?				
c. Is there vegetation (not including shade trees)?				
i. Is the vegetation neglected / unkempt?				
	0	**1-5**	**6+**	
d. Are there medium/large shade trees within the segment?				
e. Are there street lights over or near sidewalks or paths?				

Neighborhood Characteristics (2/2)	**0**	**1-2**	**3+**	NA
f. Litter				
i. Careless/Harmless				
ii. Hazardous				
iii. Cigarette Butts* (see manual)				
g. Broken/boarded up windows				

12. Are any of the following publicly available amenities present within the segment?

Publicly Available Amenities	**Yes**	**No**
a. Public trash cans (nonresidential)		
b. Seating/benches		
c. Bike rack		
d. Public art (e.g., murals, sculptures, urban furniture, neighborhood kiosks, public fountain, etc.)		
e. Public attractive natural features (e.g., notable public landscaping, gardens, parks or green spaces, pond)		

13. Are the following signs visible in the segment?

Neighborhood Signs	**0**	**1-2 sm**	**1+ lg or 3+ sm**
a. Neighborhood/social/cultural message or event			
b. Political message or event			
c. Religious message or event			
d. Fast food ads (e.g., billboards, signs outside restaurants—other than logo/name only, etc.)			
e. Alcohol ads (e.g., billboards, special offer ads, neon signs, etc.)			
f. Tobacco ads (e.g., special offer ads, signs outside stores, etc.)			
g. Security warning sign or message that suggests crime or risk of crime in the area (e.g., abduction flier, neighborhood watch, no trespassing sign, no loitering sign, etc.)			
h. Graffiti (See Manual)			

14. Are people engaging in the following activities visible within the segment?
If yes, specify if more or less than 5 people.

Activities	**Yes 1-5**	**Yes 6+**	**No**
a. Walking			
b. Biking			

c. Engaging in other physical activities (e.g., jogging, playing a sport, etc.); Specify activities: ______________________			
d. People loitering, acting hostile, threatening			
e. Homeless people or panhandlers			

f. Aggressive, uncontrolled dogs or stray animals.			

INTERSECTIONS Analysis

Conducted independently from segments

15. Describe the following **INTERSECTION** characteristics:

Intersection Characteristics	**Enter #**	
a. Traffic Lanes (including turning lanes)		
b. Pedestrian crosswalks **(If 1+, see scenarios in the manual)** ☐ **A** ☐ **B** ☐ **C** ☐ **D** ☐ **E** ☐ **F**		
i. How many pedestrian crosswalks have missing pieces or sections worn off? (within the segment)		
c. Walk/Don't Walk signals (See manual)		
d. Ramps or curb cuts (See Manual)		
	Yes	**No**
e. Pedestrian safety signs and devices		
f. Medians or pedestrian islands		
i. Pedestrian Pushbutton on Median		
g. Traffic calming devices		
Traffic Volume within the Intersection		
h. How many cars, trucks, and other motorized vehicles travel through the intersection (in any direction) during 2 minutes? ☐ **0** ☐ **1-4** ☐ **5-15** ☐ **16-34** ☐ **35+** check if NA: ☐ If NA, give reason: ________________		

Please use the below space for additional comments:

____

Appendix B: SHOW Physical Activity Questionnaire

SHOW 2010
Physical Activity and Physical Fitness (PAQ)

SPID#_____________ Date:______________ Interviewer#_____________

Revised 12/1/09 1-11 PAQ

*The next series of questions are about physical activities that you/SP have/has done over the **past 30 days**. First I will ask about activities that are related to transportation. Then I'll ask about*
daily activities, and finally, about physical activities during leisure time.

PAQ.020. Over the **past 30 days**, have you walked or bicycled as part of getting to and from work, or school, or to do errands?

Yes **1**

No **2 (PAQ.030)**

Unable to do activity **3 (PAQ.030)**

Refused **77 (PAQ.030)**

Don't know **99 (PAQ.030)**

PAQ.025. Over the past 30 days, **how often** did you bike or walk to work, school or to do errands?

PROBE: [If NEC: How many **days** per week, or per month did you do these activities?]

Enter number of days per week, or month)

Refused **777 (PAQ.030)**

Don't know **999 (PAQ.030)**

Enter Unit

Day **1**

Week **2**

Month **3**

SHOW Physical Activity and Physical Fitness (PAQ)

revised 12/1/09 1-11 PAQ

PAQ.026. On those days when you walked or bicycled, about **how long** did you spend altogether doing this?

|___|___|___|
Enter number of (minutes or hours)

Refused **777**

Don't know **999**

Enter Unit

Minutes **1**

Hours **2**

PAQ.030. Over the **past 30 days**, did you do any tasks in or around your home or yard for **at least 10 minutes** that required moderate or greater physical effort? By moderate physical effort I mean, tasks that caused **light** sweating or a **slight to moderate increase** in your heart rate or breathing, such as raking leaves, shoveling snow, mowing the lawn or heavy cleaning.

Yes **1**

No **2 (skip to PAQ.060)**

Unable to do activity **3 (skip to PAQ.060)**

Refused **77 (skip to PAQ.060)**

Don't know **99 (skip to PAQ.060)**

PAQ.040. Over the **past 30 days**, how often did you do tasks in or around the home or yard that required at least moderate effort, such as raking leaves, shoveling snow, mowing the lawn or heavy cleaning?

If NEC: How many days per week, or per month did you do these activities?

|___|___|___|
Enter number of days per week, or month)

Refused **777 (PAQ.060)**

Don't Know **999 (PAQ.060)**

Enter Unit Week **1** Month **2**

SHOW Physical Activity and Physical Fitness (PAQ)
revised 12/1/09 1-11 PAQ

PAQ.050. About how long did you do these tasks **each time**? (If more than one task, ask for task done most often.)

|___|___|___|
Enter number of minutes or hours

Refused **777**

Don't Know **999**

Enter Unit

Minutes **1**

Hours **2**

PAQ.060. Please tell me which of these four sentences **best** describes your usual daily activities? (This could include work, housework, attending classes or other daily activities) (**HAND CARD)**

Sit during the day and don’t walk about very much **1**

Stand or walk about quite a lot during the day, but
do not have to carry or lift things very often **2**

Lift or carry light loads,
or climb stairs/hills often **3**

Do heavy work or carry heavy loads **4**

Refused **77**

Don't know **99**

SHOW Physical Activity and Physical Fitness (PAQ)

revised 12/1/09 1-11 PAQ

*The next questions are about physical activities including exercise, sports, and physically active hobbies that you/SP may have done during leisure time or at school over the **past 30 days**. First I will ask you about **vigorous** activities that cause **heavy** sweating or **large increases** in breathing or heart rate. Then I will ask you about **moderate** activities that cause only **light** sweating or a **slight to moderate increase** in breathing or heart rate.*

PAQ.070. Over the past 30 days, did you do any **VIGOROUS** activities for at least 10 minutes that caused heavy sweating, or large increases in breathing or heart rate?

Some examples are running, lap swimming, aerobics classes, or fast bicycling. Here are some other examples of these types of activities. Please do not include house work or yard work that you have already told me about. **(HAND CARD WITH LIST OF ACTIVITIES LISTED IN PAQ.071)**

Yes **1**

No **2** (PAQ.080)

Unable to do activity **3** (PAQ.080)

Refused **77** (PAQ.080)

Don't know **99** (PAQ.080)

PAQ.080. Over the past 30 days, did you do **MODERATE** activities for **at least 10 minutes** that caused only **light** sweating or a **slight to moderate increase** in breathing or heart rate? Some examples are brisk walking, bicycling for pleasure, golf, or dancing. Here are some other examples of these types of activities. Please do not include house work or yard work that you have already told me about. **(HAND CARD PAQ 081)**

Yes **1**

No **2** (PAQ.090)

Unable To Do Activity **3** (PAQ.090)

Refused **77** (PAQ.090)

Don't Know **99** (PAQ.090)

SHOW Physical Activity and Physical Fitness (PAQ)

revised 12/1/09 1-11 PAQ

PAQ.090. Over the **past 30 days**, did you do any physical activities specifically designed to **strengthen** your muscles such as lifting weights, push-ups or sit-ups? Include all such activities even if you have mentioned them before.

Yes **1**

No **2 (PAQ.100)**

Unable to do activity **3 (PAQ.100)**

Refused **77 (PAQ.100)**

Don't know **99 (PAQ.100)**

PAQ.095. Over the **past 30 days**, how often did you do these strengthening physical
activities?

[IF NEC: How many times per week or month?**]**

|___|___|___|
Enter number of times per, week, or month)

Refused **777**

Don't know **999**

Enter Unit

Week **1**

Month **2**

PAQ.100. compare How does the amount of activity that you reported for the **past 30 days**

with your physical activity for the **past 12 months**? Over the **past 30 days**, were you…?:

More active **1**

Less active **2**

About the same **3**

Refused **77**

Don't know **99**

SHOW Physical Activity and Physical Fitness (PAQ)

revised 12/1/09 1-11 PAQ

PAQ.110 Compared with most men/women your age, would you say that you are…?

More active **1**

Less active **2**

About the same **3**

Refused **77**

Don't know **99**

PAQ.120. **[Asked only of those 30 or older]** Compared with yourself **10 years ago**, would you say that you are…?

More active **1**

Less active **2**

About the same **3**

Refused **77**

Don't Know **99**

Now I will ask you about TV watching and computer use outside of your regular work hours.

PAQ.130. Over the **past 30 days**, on average how many hours per day did you sit and watch TV or videos {outside of work}? Would you say…?

Less than 1 hour **0**

1 hour **1**

2 hours **2**

3 hours **3**

4 hours **4**

5 hours or more **5**

None--does not watch TV or videos **8**

Refused **77**

Don't know **99**

SHOW Physical Activity and Physical Fitness (PAQ)

revised 12/1/09 1-11 PAQ

PAQ.140. Over the **past 30 days**, on average how many hours per day did you use a computer or play computer games {outside of work}? Would you say…?

Less than 1 hour **0**

1 hour **1**

2 hours **2**

3 hours **3**

4 hours **4**

5 hours or more **5**

None--does not use a computer outside work **8**

Refused **77**

Don't know **99**

END TIME OF IN HOME INTERVIEWS:______________________

TURN OFF TAPE RECORDER BEFORE TRACKING AND TRACING MODULE

Appendix C: SHOW Neighborhood Questionnaire

Section H: Characteristics of Your Neighborhood

QH-1. **About how many minutes would it take to walk from your home to the nearest of these facilities?**

	10 minutes or less ▼	11 to 20 minutes ▼	21 to 30 minutes ▼	More than 30 minutes ▼	Don't know of any of these within walking distance ▼
1a. Park, playground, or playing field?	○	○	○	○	○
1b. Public recreation center?	○	○	○	○	○
1c. Trail for walking or biking?	○	○	○	○	○
1d. Public outdoor swimming pool?	○	○	○	○	○
1e. Public indoor swimming pool?	○	○	○	○	○
1f. Private fitness center?	○	○	○	○	○
1g. Convenience or small grocery store?	○	○	○	○	○
1h. Supermarket?	○	○	○	○	○
1i. Post office?	○	○	○	○	○
1j. Library?	○	○	○	○	○
1k. Elementary school?	○	○	○	○	○
1l. Other school?	○	○	○	○	○
1m. Fast food restaurant?	○	○	○	○	○
1n. Other restaurant?	○	○	○	○	○
1o. Pharmacy or drug store?	○	○	○	○	○
1p. Salon or barber?	○	○	○	○	○
1q. Other type of store?	○	○	○	○	○
1r. Place of worship?	○	○	○	○	○
1s. Indoor fitness facility	○	○	○	○	○
1t. Golf course	○	○	○	○	○

2. How would you rate your community as a place to be physically active?

- ◯ Not at all pleasant
- ◯ Not very pleasant
- ◯ Somewhat pleasant
- ◯ Very pleasant

3. How safe from crime is your community for walking or riding a bike?

- ◯ Not at all safe
- ◯ Not very safe
- ◯ Somewhat safe
- ◯ Very safe

4. How safe from traffic is your community for walking or riding a bike?

- ◯ Not at all safe
- ◯ Not very safe
- ◯ Somewhat safe
- ◯ Very safe

5. Please rate your degree of agreement with the following statements:

	Strongly disagree ▼	Disagree ▼	Agree ▼	Strongly agree ▼
5a. There are many destinations to go to within easy walking distance from my home	◯	◯	◯	◯
5b. There are many interesting things to look at while walking in my community	◯	◯	◯	◯
5c. My community is well maintained	◯	◯	◯	◯
5d. My community is generally free from garbage, litter, or broken glass	◯	◯	◯	◯
5e. I have easy access to fresh fruits and vegetables in my community	◯	◯	◯	◯