Public Park System Characteristics Associated with Physical Activity

Orion T. Stewart

A dissertation
submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

University of Washington
2017

Reading Committee:
Anne Vernez Moudon, Chair
Edmund Seto
Brian E. Saelens
Alyson J. Littman

Program Authorized to Offer Degree:
Epidemiology - Public Health

University of Washington

Abstract

Public Park System Characteristics Associated with Physical Activity

Orion T. Stewart

Chair of the Supervisory Committee:
Anne Vernez Moudon, Professor Emerita
Department of Urban Design and Planning

Physical activity (PA) is protective of many chronic diseases, but most Americans are not sufficiently active. Public parks are places where PA occurs, and thus expanding park land or the facilities in parks could result in greater population levels of PA. There is a lack of robust evidence, however, linking greater park proximity or more or better park facilities with higher PA levels at the individual level. In this dissertation, we identified and characterized park visits and corresponding park-based PA using timestamp-linked travel diary, GPS, and accelerometer data collected from a population-based sample of urban King County adults observed for one to three one-week periods over 4 years. Using these data, we sought to advance the understanding of how park proximity and facilities in parks are associated with PA.

In *Aim 1* we assessed how proximity to parks is associated with PA. We divided total PA bout time into three mutually exclusive categories: PA that occurred during visits to home neighborhood parks, PA that occurred during visits to non-home neighborhood parks, and all other PA. We found that home neighborhood park proximity (count and area of parks within a 10-minute walk) was positively associated with home neighborhood park PA. But since home neighborhood park PA accounted for an average of only 3% of total PA, home neighborhood park proximity was not associated with total PA.

In *Aims 2A* and *2B* we tested the association between the variety of facilities in parks and PA. In *Aim 2A* we treated individual participants as their own controls to compare the variety of PA facilities in different parks that an individual visited while active versus sedentary. We found that each additional different type of PA facility in a park was associated with a 7% increased probability of an individual being active during a visit.

In *Aim 2B* we assessed if the variety of PA facilities at a park was associated with duration of PA during a park visit. We observed that each additional different type of PA facility in a park was independently associated with a 7.3% greater duration of PA during the park visit.

Our findings based on comprehensive and objective park visit data provide strong evidence for an association between parks and individual-level PA, but also place the association in the context of overall PA. Because park-based PA is a small proportion of total PA, investing in parks should be viewed as one of a portfolio of strategies to create an overall environment more conducive to physical activity.

Table of Contents

List of Figures

List of Tables

Acknowledgements

This dissertation developed out of my work at the Urban Form Lab. It would not have been possible if not for the support of the lab's director, Professor Anne Vernez Moudon. Professor Moudon also served as the chair of my dissertation committee, in which she provided the guidance and gentle pressure necessary to help transform a relatively minor work task into a full-fledged dissertation.

The Travel Assessment and Community (TRAC) Project provided the data for this research. The project was funded by the National Institutes of Health (R01HL091881). I must thank Brian Saelens, TRAC's Primary Investigator and member of my committee, for his input on this dissertation and professional management of the larger TRAC Project.

I also owe a thanks to all of those at the Seattle Children's Research Institute and the Urban Form Lab who helped make the TRAC Project – and therefore my dissertation – possible. Phil Hurvitz fits squarely under this category. Phil must also be recognized for his technical mentorship, which went above and beyond any work duty. I wouldn't have made it very far in the analysis if not for Phil.

Thanks to Alyson Littman and Edmund Seto, my dissertation committee members who were not directly involved in the TRAC project, for their valuable insights and outsider perspectives. Thanks to them, those not directly involved in the TRAC project will be able to understand my dissertation!

And finally thanks to my wife Skye and my daughter Silvia, who helped me actually get out to parks for a breath of fresh air during this process.

Introduction

Physical Activity (PA) is associated with reduced risk of cardiovascular disease, obesity, diabetes, osteoporosis, and some cancers (Physical Activity Guidelines Advisory Committee 2008). Yet more than 90% of adults in the U.S. do not meet the recommended 30 minutes/day of moderate-to-vigorous PA on most days of the week (Troiano, Berrigan et al. 2008). Physical inactivity is estimated to cost more than $76 billion per year in direct medical expenses (Pratt, Macera et al. 2000), and along with overweight/obesity account for 27% of national health care charges (Anderson, Martinson et al. 2005). The socio-ecological model of behaviors and health identifies multiple levels of influence on an individual's PA (Sallis 2009), and thus multiple levels of intervention. The levels range from biological processes to national policies. While the most effective interventions are hypothesized to address multiple socio-ecological levels, the built environment (built features of the physical environment), is believed to be particularly important (Sallis, Floyd et al. 2012). The built environment (BE) provides settings for PA, is readily modifiable, and modifications will affect the lives of many individuals in a community. Indeed, the US National Physical Activity Plan advocates increasing access to places for PA to increase population levels of PA (US National Physical Activity Plan Coordinating Committee 2010). Public parks are places for PA, with a median of 21 minutes of light or more intense PA occurring during visits made by Seattle area adults (Stewart, Moudon et al. 2016). Public parks are also particularly appealing because, unlike private facilities, there are no financial barriers to entry.

Conceptual framework of park characteristics that contribute to PA

Parks contribute to PA through their visitation and the corresponding activities that occur within the park (e.g., sports) or during active travel to or from the park (e.g., walking). Park visitation and corresponding PA depends on an interactive relationship between the characteristics of the visitor and the park. Characteristics of park visitors include age, race, gender, and socio-economic status, with park visitors tending to be younger adults, white, male, and of higher incomes (Lee, Scott et al. 2001). Park characteristics were theorized by Bedimo-Rung et al. (2005) as six conceptual domains that operate through four geographic areas. The six conceptual domains include features, condition, access, aesthetics, safety, and policies. The four geographic areas include activity areas (places that are designed or commonly used for physical activity, such as basketball courts or playgrounds), supporting areas (areas in a park that make PA comfortable, such as restrooms or picnic areas), the overall park environment (the overall size, aesthetics, diversity of programs, demographic usage, and/or accessibility), and the surrounding neighborhood (since users must travel through a park's surrounding neighborhood to access the park, the surrounding neighborhood likely influences if a park is visited and how it is used).

The Bedimo-Rung conceptual framework serves as a guide for operationalizing and measuring park characteristics for research on the relationship between park characteristics and park-based PA (Bedimo-Rung, Gustat et al. 2006). The bulk of research on this topic has focused on the conceptual domains of park access and features. This is reasonable, as one must have access to a park and its features for any PA to occur, whereas one can still obtain PA in parks that are accessible but are poorly maintained or have unappealing aesthetics and unsafe conditions. In theory, park access and features are also straightforward to modify through direct capital investments to develop additional parks or build additional facilities within existing parks. A solid evidence base is important, however, to ensure that such capital investments are spent wisely. For all of these reasons, we focus our attention on park access and features.

Park access and PA

Park access can be defined as the means of entering a park, which is a function of the interaction of individual and park characteristics and results in an individual- and park-specific definition of access. Distance between the individual (e.g., from home residence) and the park is one clear example of the interaction between park and individual characteristics that helps determine and individual's access to a park. But other factors, such as safety and mobility, may also impact accessibility. For example, an individual may live across the street from a park, but perceive it as dangerous and therefore inaccessible. For the purpose of research in which measuring accessibility for each unique individual-park combination is not feasible, park access is simplified to only capture proximity to home. This operationalization of access implies that all parks are universally accessible save for varying travel times to get to the park. Home-based park proximity measures include distance to the closest park as well as count or area of parks within a certain distance from home (Zhang, Lu et al. 2011).

Cohen et al. (2007) sampled adults from in or around specific parks and found that shorter distances from the specific park to home were associated with higher levels of its use for PA. This park-based research approach, however, fails to capture how the broader park landscape (i.e., the potential for multiple parks near an individual's home) contributes to park-based and total PA.

Studies using population-based adult samples (i.e., samples not drawn within or near specific parks) have also yielded associations between park proximity and self-reported PA. Park access – variously defined as the number of parks or area of parkland near home – has been associated with greater levels of PA among adults (Coombes, Jones et al. 2010, Kaczynski and Mowen 2011, Kaczynski, Besenyi et al. 2014), even after controlling for residential self-selection, or the possibility that active persons seek out neighborhoods more endowed with active resources (Kaczynski, Besenyi et al. 2014). But this body of evidence linking park access to PA is based on self-report measures of park use as well as park-based and overall PA, which are subject to social desirability and recall biases (Sallis and Saelens 2000). Studies that have overcome these biases through the use of objectively measured PA are less encouraging. Of the 7 studies Bancroft et al. (2015) identified in a systematic review of research testing the association between park proximity and objectively measured total PA among adults, 6 had non-significant results (King, Belle et al. 2005, Jilcott, Evenson et al. 2007, McConville 2009, Carlson, Sallis et al. 2012, Saelens, Sallis et al. 2012, Strath, Greenwald et al. 2012). The single study that reported a significant positive association was conducted among older women and observed an unadjusted 27% greater median daily pedometer step count among those who reported living within walking distance of a park (King, Brach et al. 2003, Wieters 2009). In addition to being conducted among a population that may lack generalizability, this study had two other major limitations: first, self-report park proximity has very poor agreement with objective park proximity (Lackey and Kaczynski 2009) and second, failure to adjust for other built environment characteristics that affect 'walkability' in the home neighborhood could result in spurious relationship between home neighborhood parks and total pedometer steps if many of those steps occurred in places other than home neighborhood parks. Regarding the second limitation, parks comprise just one aspect of the neighborhood environment and park presence is correlated with more urban built environments (Zhang, Lu et al. 2011), which have other characteristics such as high densities of streets and other destinations that could contribute to greater or lower levels of walking.

To our knowledge, no study has used objective measures of both home-based park proximity and park-based PA outcomes to assess the direct contribution of home neighborhood parks to total PA among a general adult population while also controlling for individual and neighborhood built environment factors related to both park presence and PA.

Park facilities and PA

Several studies using population-based samples (i.e., samples not drawn within or near specific parks) found the presence of certain features in parks near individuals' homes to be associated with these individuals' neighborhood park-based PA (Giles-Corti, Broomhall et al. 2005, Kaczynski and Havitz 2009, Sugiyama, Francis et al. 2010, Kaczynski, Besenyi et al. 2014). But these studies do not provide strong evidence that specific facilities directly result in more PA, since the facilities measured in neighborhood parks may not directly correspond to the specific neighborhood parks that were actually used for PA. This limitation was addressed in a study of 1,305 adults in Odense, Denmark (Schipperijn, Bentsen et al. 2013). The number of PA facilities in the closest park to one's home was positively associated with the likelihood of PA in the closest park occurring at least once a week, but the association did not remain after adjusting for park size, suggesting that area of parkland may be more important for park-based PA than the number of facilities in a park.

Studies using direct observation of park users provide stronger evidence that the number and types of park facilities are associated with higher levels of park-based PA. Comparisons of active park visitors to sedentary park visitors in the same parks found that active park visitors were more likely to be in park areas with any PA facilities, such as courts, paths, and playgrounds (Shores and West 2008, Floyd, Bocarro et al. 2011). Additionally, pretest-posttest studies show that installing or upgrading park PA facilities more often (Tester and Baker 2009, Cohen, Marsh et al. 2012, Veitch, Ball et al. 2012) than not (Cohen, Golinelli et al. 2009) led to increases in observed levels of park-based PA. These direct observation studies suggest that park visitors are more active in park settings with PA facilities, and there may be a latent demand for PA facilities. Direct observation of park users, however, cannot provide insight into how PA facilities may change an individual's behavior in a park. For example, in parks with a greater variety of facilities are visitors more likely to be active, or are do active visitors visit more frequently and stay longer?

Observing the mechanism: park visits

Life segment epidemiology provides a promising approach to overcoming the limitations of population- and park-based studies (Chaix, Kestens et al. 2016). The life segment approach observes individuals drawn from a population over a period of time, then identifies and analyzes specific behaviors – or life segments – of interest, in this case park visits. Park visit data enable researchers to observe the mechanism through which parks contribute to total individual-level PA. Activity diaries and GPS devices used in conjunction with detailed park data have recently enabled researchers to pinpoint visits to specific parks and any corresponding PA. For example, Kaczynski et al. (2008) linked park visits recorded in PA diaries to geographic information system (GIS) data on 33 neighborhood parks and found that the number of different facilities was associated with a doubling in the odds of whether a park was visited for PA by any of 380 adult study participants, controlling for park size and average distance to participants' homes. This study suggests that the variety of park facilities affect park-related PA, but the aggregate outcome measure of any study participant using the park for PA limits inference as to how park facilities are associated with a single individual's park activity. Furthermore, the study does not provide insight into how facilities may be associated with the duration and/or intensity of park-related PA. This was investigated more recent by Evenson et al. (2013), who used accelerometer and GPS instruments to objectively measure park-based PA among 238 adults sampled among park users or those living close to parks. Park visits were identified by spatially overlaying GPS-derived locations with park GIS data. Almost 15 minutes of light-to-vigorous PA occurred during the average 53.3-minute park visit. Evenson et al.'s study quantified the intensities and durations of PA that occurred during park visits, but did not assess whether park characteristics were associated with them. Stewart et al. (2016) identified park visits using both GPS and travel diary data and found that park visitation alone did not explain higher levels of overall PA among those who visited parks, but also failed to assess whether park characteristics were associated with park-based PA.

In this dissertation, we apply a life-segment approach to advance the understanding of how park proximity and facilities in parks are associated with PA. We identify park visits and corresponding park-based PA using timestamp-linked travel diary, GPS, and accelerometer data collected from a population-based sample of urban King County adults observed for up to 3 one-week periods over 4 years. We apply these data to 3 specific research questions:

- In *Aim 1* we divide total PA bout time into three mutually exclusive categories: PA that occurred during visits to home neighborhood parks, PA that occurred during visits to non-home neighborhood parks, and all other PA. We test the hypothesis that home neighborhood park proximity (count and area of parks in the home neighborhood) is positively associated with home neighborhood park PA and accounts for any observed positive association between home neighborhood park proximity and total PA, controlling for sociodemographics and home neighborhood built environment characteristics.
- In *Aim 2A* we treat individual participants as their own controls and compare the variety of PA facilities in parks that an individual visited while active to parks the same individual visited while sedentary. We hypothesize that, after controlling for other park and park neighborhood characteristics, a greater variety of PA facilities in a park will be associated with an increased likelihood of an individual being active during a visit.
- In *Aim 2B* we continue to assess how the variety of PA facilities at a park is associated with individual-level PA during a park visit. We test the hypothesis that a greater variety of PA facilities will be associated with an increased duration of PA, controlling for any confounding characteristics of the park visit, individual visitor, and park.

Combined, these aims are intended to provide a more complete understanding of the nuanced ways in which the spatial layout of park systems and the facilities within individual parks may contribute to PA and in turn reduce the risk of diseases associated with inactivity. It is our hope that this knowledge will result in park systems optimized for the health and well-being of the populations they serve.

Aim 1: How are home neighborhood parks associated with physical activity?

Abstract

Public parks can support physical activity (PA) among nearby residents. Yet few studies have observed an individual-level association between proximity to parks and objectively measured PA. This study explored how parks within the home neighborhood (833m street network buffer) are associated with PA using objectively measured park and PA data collected from a cohort of urban, community-dwelling adults in the Seattle area.

The sample included 634 adults with at least one park in the home neighborhood observed using time-matched accelerometer, GPS, and travel diary instruments for up to 3 weeklong periods over 4 years. Accelerometer-derived total mean daily PA bout minutes were divided into home neighborhood park PA, non-home neighborhood park PA, and other PA. Mixed effects negative binomial regression was used to test the association between count and area of home neighborhood parks and the 4 PA measures.

On average, only about 11% of the 43 minutes of mean daily total PA time was park related, and only 3% of total PA time was related to home neighborhood parks. After controlling for socio-demographics and home BE covariates, positive relationships were observed between both home neighborhood park count and area and home neighborhood park PA. No associations were observed between park count or area and other PA or total PA. Home neighborhood park count was positively associated with non-home neighborhood park PA; for park area the association was negative. Exploratory analysis showed that associations varied by household composition (presence of children and dogs) and by home neighborhood buffer size.

The small proportion of total PA related to home neighborhood park use may explain why greater proximity to parks has not consistently been associated with increases in overall PA. However, greater proximity to home neighborhood parks does appear to increase PA related to their use, especially among adults with children and/or dogs in their household. Furthermore, the spatial structure of the park system may influence active recreational travel and the location of park-based PA. Park managers and planners should consider these factors when designing park systems to optimally support PA.

Introduction

Physical activity (PA) is associated with reduced risk of cardiovascular disease, obesity, diabetes, osteoporosis, and some cancers (Physical Activity Guidelines Advisory Committee 2008). Yet more than 90% of adults in the U.S. do not meet the recommended 30 minutes/day of PA on most days of the week (Troiano, Berrigan et al. 2008). Parks are places that could support PA among adults, both as settings for activities and destinations for active travel (Evenson, Wen et al. 2013, Stewart, Moudon et al. 2016). A greater number of parks and area of parkland in close proximity to home could potentially result in higher levels of physically activity and reduced risk of negative health outcomes. However, a systematic review exploring the association between park proximity and objectively measured PA across all age groups was inconclusive (Bancroft, Joshi et al. 2015). Of the 7 studies Bancroft et al. (2015) reviewed that were conducted among adults, 6 had non-significant results (King, Belle et al. 2005, Jilcott, Evenson et al. 2007, McConville 2009, Carlson, Sallis et al. 2012, Saelens, Sallis et al. 2012, Strath, Greenwald et al. 2012). The single study that reported a positive association was conducted among older women and observed an unadjusted 27% greater median daily pedometer steps among those who reported living within walking distance of a park (King, Brach et al. 2003, Wieters 2009). This body of literature proves frustrating to urban planners, public park managers, and health professionals who know that parks provide a PA setting for nearby residents based on interviews of park visitors (Cohen, McKenzie et al. 2007), but lack strong evidence that increasing access to parks will result in increases in PA.

Mostly null findings on the association between park proximity and objective PA could be due to several study design and analysis choices, including measures of home park exposure, measures of PA outcomes, sample populations, and covariates included in analyses. Use of a specific park is related to the distance from it to an individual's home (Cohen, McKenzie et al. 2007), and thus park-PA associations tend to be stronger using smaller home neighborhood buffer sizes to measure park exposure (Bancroft, Joshi et al. 2015). Parks support a variety of PA, but are most commonly used for lighter-intensity activities like walking (Godbey and Mowen 2010), so stronger associations may be observed for lighter intensity PA. Although walking is common, activity levels during park use vary by race/ethnicity, gender, and other socio-demographic characteristics (Carlson, Brooks et al. 2010, Kaczynski, Wilhelm Stanis et al. 2011, Cohen, Han et al. 2016). In addition, household composition (e.g., presence of children and/or dogs) may also influence park visitation and activity levels. Parks also comprise just one aspect of neighborhood environments and their presence may be correlated with other urban built environment (BE) characteristics that affect active living (Zhang, Lu et al. 2011). Individuals with many proximal parks close to home may also have many other PA opportunities close to home where they obtain their PA. Additionally, the distribution and quality of parks varies with neighborhood poverty and other aspects of the social environment (Abercrombie, Sallis et al. 2008, Chaix, Kestens et al. 2016), which also may influence PA, both in neighborhood parks and in the neighborhood generally. And finally, associations that are observed between park proximity and PA could be biased by residential self-selection, in which observed relationships between the home neighborhood BE and PA are influenced in part by the propensity for more active individuals to choose to live in neighborhoods supportive of PA (Cao, Mokhtarian et al. 2009). To our knowledge, no study examining the link between home neighborhood parks and PA has fully accounted for these complexities while using objective park exposure and PA outcome measures.

This study is intended to address the shortcomings in the literature. We aim to not only test *if* neighborhood parks are associated with PA, but *how* neighborhood parks are associated with PA. To do this, we start by using data from a population-based study of urban-living adults whose activity was tracked using GPS, accelerometer, and travel diary instruments. These instruments provide contextual data on where PA occurs, and allow for much greater specificity for research examining the link between the built environment and health-related behaviors (Hurvitz, Moudon et al. 2014). In this study, total PA is binned into three mutually exclusive categories: PA that is related to home neighborhood park visits, PA that is related to park visits elsewhere, and PA that is not related to park visits. These three distinct PA contexts and locations are then tested for an association with home neighborhood park proximity (count and area of parks in the home neighborhood) to explore the mechanism through which home neighborhood parks may differentially contribute to the three PA contexts/locations to affect total PA.

In addition to analyzing detailed contextual measures of PA in relation to home neighborhood parks, we also isolate the effect of parks on PA by controlling for several socio-demographic and home neighborhood built environment characteristics that could influence park access and use. We explore whether residential self-selection bias is present, whether household composition modifies the effect of parks on PA, and whether the association changes using smaller versus larger definitions of the home neighborhood. Combined, these analyses are intended to provide a more complete understanding of the nuanced ways in which home neighborhood parks may contribute to PA and in turn reduce the risk of diseases associated with inactivity.

Methods

Study design and sample

In this study we use repeated cross-sectional data from the Travel Assessment and Community (TRAC) project. The TRAC project was a longitudinal study of travel and activity in relation to light rail implementation in King County, Washington. The sample frame included King County residents in areas proximal (<1 mile) or distal (>1 mile) from planned light rail stations, but with otherwise similar built environments (Moudon, Saelens et al. 2009). Parcel-based sampling was used to identify households located in the sample frame (Lee, Moudon et al. 2006). Households were contacted by telephone between July 2008 and July 2009 and one participant per household was recruited if they were aged 18 or older, able to complete a travel diary and survey in English, and able to walk unassisted for ≥10 minutes. The Seattle Children's Hospital Institutional Review Board approved the study. A total of 699 enrolled participants completed baseline data collection, 584 and 532 of whom also completed first and second follow-up data collection, respectively. Baseline data collection occurred from July 2008 to July 2009, follow-up data collection occurred 2 and 4 years later. At each follow-up participants completed a survey and provided data on their activities for a one-week period. Follow-up data collection occurred at the same time of year for each participant.

Data collection and measures

Activity

A detailed description of the activity data collection and processing is available elsewhere (Kang, Moudon et al. 2013). Briefly, participants were instructed to wear an accelerometer (GT1M; ActiGraph LLC, Fort Walton Beach, FL, at baseline and GT3X, ActiGraph LLC, Fort Walton Beach, FL, at first and second follow-up), carry a GPS device (DG-100, GlobalSat, Taipei, Taiwan, at baseline and first follow-up and BT-1000XT GPS data logger, Qstarz, Taipei, Taiwan, at second follow-up), and complete a place-based paper travel diary for a one week period. Data from the three instruments for each participant were integrated by time matching GPS and travel diary locations to each 30-second accelerometer epoch (Hurvitz, Moudon et al. 2014). In this analysis, observation days were considered valid if they had ≥1 place recorded in the travel diary, ≥3 minutes of GPS data, ≥50% of all GPS point locations inside of King County, and an accelerometer wear time of ≥8 hours. Accelerometer periods of ≥20 minutes with continuous zeroes were considered non-wear times (Masse, Fuemmeler et al. 2005).

Parks

In spring 2008, park locations were obtained from King County government and the 39 municipalities located within it. Parks were defined as publically owned, freely accessible, outdoor spaces intended for leisure or recreation that were distinct from street right-of-ways. Thus, aquariums, boulevards, golf courses, community centers, boat launches, cemeteries and similar places not located entirely within public parks were excluded. Data not already stored in a GIS format were digitized in ArcGIS 9.2 (ESRI, Redlands, CA) with the aid of tax parcel data and aerial imagery. GIS park polygons were aggregated by unique park name for a final dataset of 1,440 discrete parks.

Park visits

Park visits were comprehensively measured using two sources: travel diaries and GPS/GIS data. For each place visited, participants recorded in the travel diary the place name and time of arrival and departure. Travel diary places were reviewed for names matching those of public parks. Matching names were considered park visits if the duration between the arrival and departure time was ≥3 minutes. Each travel diary park visit was linked to a park in the GIS database based on the park name. Park visits were also sensed from the GPS/GIS data using a method similar to that pioneered by Evenson et al. (2013). Sensed visits consisted of ≥3 minutes of consecutive GPS points in the same GIS park polygon, with a speed <30km/h and a distance of >50 meters from the participant's home and work, while allowing for gaps of ≤45 minutes. If a sensed visit temporally overlapped with a visit recorded in the travel diary, the presumably more precise duration from the GPS data was used.

Physical activity outcomes

We measured PA as time spent in bouts with lower accelerometer activity count thresholds in order to capture light PA obtained during walking, the most commonly reported form of park-based PA (Godbey and Mowen 2010). PA bouts were therefore defined as time intervals with vertical axis accelerometer counts >500 per 30-second epoch for at least 5 minutes, allowing for counts to drop below that threshold for up to 2 minutes during any 7-minute interval (Kang, Moudon et al. 2013).

Four PA outcomes were assessed in this analysis: total PA bout time as well as three mutually exclusive and exhaustive subcategories, home neighborhood park PA, non-home neighborhood park PA, and other PA. Park PA time was comprised of PA bouts that temporally overlapped any portion of park visits (Figure 1-1). This included PA bout time that occurred immediately before or after the park visit, but that was still part of a bout that consisted of at least one 30-second accelerometer epoch inside the park (Stewart, Moudon et al. 2016). PA bout time immediately before or after the park visit was included to capture active travel, such as walking or jogging, to or from the park. If a single PA bout temporally overlapped with two or more park visits, as would be the case if a participant walked through one park and continued walking to another park, the intermediate park-related PA bout time was assigned to the park visit it preceded (Figure 1-2). Park PA was further categorized by the location of the park relative to the participant's home. Home neighborhood park PA included any park PA that occurred in parks that intersected the home neighborhood buffer. Park PA that corresponded with visits to parks completely outside the home neighborhood buffer is referred to as non-home neighborhood park PA (Figure 1-2).

All other PA bouts that did not temporally overlap with a park visit were considered as other PA.

Exposure to parks

Two exposures of home neighborhood parks were measured using an 833m home neighborhood sausage buffer: park count and park area. The sausage buffer was created by identifying all pedestrian-accessible segments of the King County transportation network within 833m of the participant's home, buffering the segments by 50m, then filling in any gaps inside the buffer (Forsyth, Van Riper et al. 2012). Park count is a measure of the number of distinctly named public parks that intersect the buffer. Park area was measured as the total acreage of the parks intersecting the buffer. If only a portion of a park intersected the buffer, the entire area of the park was included in the calculation. These measures respectively represent the distinct parks and the area of parkland that can be accessed via a 10-minute walk from home. The two measures were used because of their potentially different relationships with PA and their different implications for park system design. The relatively small 833m threshold to define the home neighborhood was chosen because an association between park proximity and PA was more commonly observed by studies using smaller home neighborhood buffer sizes (Bancroft, Joshi et al. 2015). It also is similar to the 0.9km median network distance between home and parks visited where walk was the travel mode and home was the preceding place recorded in the travel diary in the present study (data not shown).

Home neighborhood built environment

The 833m home neighborhood buffer was also used to measure additional potential built environment covariates related to PA, especially walking. BE measurements are detailed in Appendix B. Briefly, seven BE variables were measured under four domains commonly used in active living research and for which secondary GIS data were available: development density, destinations, transportation systems, and economic environment (Stewart, Carlos et al. 2016). Development density variables included the number of residential units and the square footage of improvements (i.e., buildings) on land used for employment, both of which served as indicators of human activity. Count of restaurants served as an indicator of utilitarian destinations. Transportation system variables included the count of ≥3-way intersections, the length of sidewalks (km), and the size of the buffer (acres). The economic environment was measured as the average King County percentile of the assessed value of residential units (land + improvement).

Socio-demographics and other survey data

Participants' age, gender, race and ethnicity, and highest level of education were collected through the TRAC baseline survey; values were carried through to the first and second follow-ups, except for age, which was updated based on elapsed time. Age was categorized as ≤45, 45-65, or >65; race and ethnicity were categorized as non-Hispanic white or other; education was categorized as less than a college degree, 4-year college degree, or graduate degree. Annual household income (categorized as <$30,000, $30,000 - $60,000, $60,001 - $90,000, or >$90,000) and presence of children under age 18 in the household was collected at each observation period. Body Mass Index (BMI, kg/m^2) was calculated from reported weight at each observation period and height at baseline and categorized as underweight or normal (≤25), overweight (25-30), and obese (>30). The number of adults in the household and the number of drivable cars were also collected at each data collection period and were used to calculate the ratio of cars to adults as a measure of transportation options. Single family vs. other residence types (apartment, condo, townhouse, other) was collected at all waves and was included as a proxy for presence of outdoor green space at home as an alternative to the outdoor green space that parks provide. Importance of "closeness to open space (e.g. parks)" as a reason for neighborhood selection measured on a 5-point Likert scale was only assessed in the baseline survey while dog ownership was collected only at first and second follow-up. Parks as a reason for moving to one's neighborhood was trichotomized as not at all/not important, somewhat important, or important/very important.

Analysis

Analysis was conducted at the participant-observation period level (e.g., a participant who completed baseline and both follow ups of the study would contribute three data points). Time within each PA outcome was averaged over all valid days in each observation period.

We restricted the analytic sample to participant-observation periods with ≥1 valid day of activity data, current residences located within King County, current workplaces not located within King County parks, and non-missing data for all covariates. These inclusion criteria resulted in a sample of 605, 455, and 395 individuals at baseline, first, and second follow-up, respectively. The analytic sample was further restricted to those participants with ≥1 park in their home neighborhood and for whom it was possible to have a non-zero value of the neighborhood park-related PA outcome. This inclusion criterion removed an additional 23, 21, and 16 participants at baseline, first, and second follow-up, respectively. At baseline, compared to individuals included in the analysis with parks in their home neighborhood (n=582), those excluded with no parks (n=23) were similar in terms of socio-demographics but lived in less urbanized neighborhoods (i.e., with fewer residential units, lower employment square footage, fewer restaurants, fewer intersections, fewer km of sidewalks, and a smaller home neighborhood sausage buffer). Those excluded had lower total daily average PA bout minutes but similar levels of park-related PA (Appendix A, Table 1-3).

We first described the analytic sample in terms of observation period characteristics, socio-demographics, neighborhood BE, and average daily PA for each observation period.

For the primary analysis, we used mixed effects negative binomial regression models to test the association between the two exposure measures of home neighborhood parks (count and area) and the four outcome measures of mean daily PA time in bouts (total, home neighborhood park, non-home neighborhood park PA, and other PA). Mixed effects were included at the individual level to account for the within-participant correlation in the participant observation period-level data (Duncan, Jones et al. 1998, Diez-Roux 2000). A negative binomial link was used due to overdispersion in the distribution of the outcome PA variables (i.e., standard deviations were larger than means) and was found to have a better model fit based on AIC and BIC statistics than a Poisson link commonly used for count data (Appendix A, Table 1-4) (Agresti 2001). A zero-inflated negative binomial (ZINB) model was also considered due to the large prevalence of zeros in the park-related PA outcomes, but was not used because non-park PA outcomes did not have a large prevalence of zeros and there was an interest in comparing results across outcomes. Additionally, running a ZINB model using mixed effects for repeated measures was not feasible. Because most home neighborhood parks were relatively small but a few were very large, the exposure of home neighborhood park area was highly skewed toward 0. It was log transformed to achieve a normal distribution and better model fit. Model coefficients are presented as incident rate ratios (IRRs) and can be interpreted as the multiplicative change in mean daily PA among participants with one additional park or twice as much park area in their home neighborhood.

Three mixed-effects negative binomial regression models were fit for each exposure-outcome combination. Model 1 was used to test the crude association and only included the exposure variable and the count of valid observation days. Model 2 controlled for socio-demographics and added to model 1 the variables of age (continuous), gender, race/ethnicity, education, income, children in the household, weight status, and car-to-adult ratio. Model 3 further controlled for the neighborhood BE and added to model 2 the variables of single family home, residential units, employment square feet, restaurant count, intersection count, sidewalk length, buffer area, and neighborhood wealth.

Exploratory analyses assessed the impact of residential self-selection by further controlling for survey-reported “importance of closeness to open space” (e.g. parks) in model 3. Because the survey question was only asked at baseline, models included all baseline observations but only follow-up observations among those participants who had not moved from their baseline residence (37 and 54 participants had moved by first and second follow-up, respectively).

Effect modification was assessed for variables representing household dynamics that may alter the way adults use parks. These included children in the household and dog ownership (none vs. any for each). For dog ownership, the sample was limited to first and second follow-up periods when this question was included in the survey.

Finally, models were repeated using a larger, 2.5km definition of home neighborhood to explore how a larger definition of home neighborhood affected results. The 2.5km distance was about three times that of the 833m distance used for the main analysis and corresponded to the threshold at which driving became more likely than walking as an access mode for parks visited from home; the 2.5km distance was based on a linear regression model using travel-diary reported park visits among this study population (results not shown). In this sub-analysis, all park exposure, PA outcome, and BE covariates were measured using the 2.5km buffer.

Results

Sample characteristics

During each of three observation periods, the sample had an average of 6 valid observation days and 14 hours of accelerometer wear time per day (Table 1-1). The sample was predominantly middle-aged, female, non-Hispanic White, and college educated. One third of participants came from households with incomes of more than $90,000 annually and less than a quarter lived with children. About half the sample was overweight or obese. The mean car-to-adult ratio was slightly less than 1, and half of the sample lived in a detached single family home. About two-fifths reported that parks were very important for residential selection at baseline, and about one-fifth owned dogs at first or second follow-up. Built environment variables showed the sample lived in an urban environment: on average, participants lived within a 10-minute walk of more than 4,000 other residential units, 4.5 million square feet employment building space, and 64 restaurants. On average the sample had good access to parks, with about 5 discrete parks and 55 acres of parkland within a 10-minute walk. Visits to home neighborhood parks occurred an average of 0.4 times per week while visits to non-home neighborhood parks occurred an average of 1.1 times per week. Mean daily total PA was 42.7 minutes at baseline, with other PA (not related to parks) accounting for almost 90% (38.0 minutes). Home neighborhood park PA only accounted for 3% of mean daily total PA (1.2 minutes), and other park PA accounted for 8% of mean daily total PA (3.4 minutes).

Primary analysis

For the exposure of count of home neighborhood parks, a positive crude association was observed for all PA outcomes (Table 1-2). Adjusting for socio-demographics in model 2 resulted in slightly stronger associations for both home and non-home neighborhood park PA outcomes, and slightly weaker associations for other and total PA. Further adjusting for the home neighborhood built environment in model 3 eliminated the associations between park count and other and total PA, while further strengthening the associations between park count and both park PA outcomes. Model 3 results estimated home park mean daily PA to be 9% greater for each additional park in the home neighborhood (IRR = 1.09; 95% CI: 1.00, 1.18; p=0.039); non-home neighborhood park mean daily PA was estimated to be 5% greater for each additional park in the home neighborhood (IRR = 1.05; 95% CI: 1.01, 1.10; p=0.020).

For the exposure of area of home neighborhood parks, a positive crude association was observed only for home neighborhood park PA (Table 1-2). Adjusting for socio-demographics in model 2 resulted in a slightly stronger association between park area and home neighborhood park PA as well as a significant negative association for other PA. Further adjusting for the home neighborhood built environment in model 3 eliminated the association with other PA, and resulted in a positive association for PA in home neighborhood parks and a negative association for mean daily PA in non-home neighborhood parks. Results from model 3 estimated home park mean daily PA to be 54% greater for each doubling of park area in the home neighborhood (IRR = 1.54; 95% CI: 1.34, 1.77; p<0.001); non-home neighborhood park mean daily PA was estimated to be reduced by 7% for each doubling of park area in the home neighborhood (IRR = 0.93; 95% CI: 0.86, 1.00; p=0.045).

Exploratory analyses

We explored potential residential self-selection bias by further controlling for neighborhood selection related to parks. After adjustment, model 3 results remained unchanged (Appendix A, Table 1-5).

We investigated effect modification by presence of children and dogs in the household by comparing model 3 results by strata of each of these variables, as well as testing an interaction term in a full sample model. Home neighborhood park count had a stronger positive relationship with home park PA and weaker positive relationship with non-home park PA among participants with at least one child compared to no children in the household (Appendix A, Table 1-6). The opposite trend was observed for home park area. A larger effect modification was observed for dog ownership (Appendix A, Table 1-7). No association between home neighborhood park count and home park-related PA was observed for those without a dog. However, dog owners were estimated to have daily mean minutes of home neighborhood park-related PA 104% greater for each additional home neighborhood park (IRR = 2.04; 95% CI: 1.41, 2.97; $p<0.001$). All other exposure-outcome relationships were similar among those who did and did not own a dog.

Defining the home neighborhood using a 2.5km buffer resulted in roughly half of park PA occurring in the home neighborhood (Appendix A, Table 1-8). Home neighborhood park-PA associations were slightly different: For park count, we observed a significant positive relationship with non-home neighborhood park PA only. Home neighborhood park area was significantly positively associated with home neighborhood park PA, other PA, and total PA; but not with non-home neighborhood park PA (Appendix A, Table 1-9).

Discussion

In this study we connected objectively measured PA by context (park-based or not) with location (parks in the home neighborhood or not) to determine how home neighborhood parks contribute to PA. Even among our sample of urban adults with an average of 5 parks in their neighborhood – defined as the area accessible within a 10-minute walk from home – park PA accounted for only 11% of total PA, and home neighborhood park PA accounted for an even smaller proportion (3%). In our sample, not much PA occurred in home neighborhood parks. If parks in the home neighborhood contribute to total PA only through home neighborhood park PA, then it is not surprising that many prior studies found no association between proximal parks and total PA (King, Belle et al. 2005, Jilcott, Evenson et al. 2007, Carlson, Sallis et al. 2012, Saelens, Sallis et al. 2012, Strath, Greenwald et al. 2012). They simply lacked specificity. Any increase to the roughly 3% of total PA that occurs in home neighborhood parks as their size or number increases will be lost in the noise of the other 97% of PA that occurs elsewhere and is not affected.

Having the specificity to do so, we tested the association between home neighborhoods parks and total PA as well as three categories: home neighborhood park PA, non-home neighborhood park PA, and other PA. After controlling for socio-demographics and the home neighborhood BE, the count and area of home neighborhood parks were both positively associated with PA corresponding with their visitation, but not with other PA nor with total PA. These results were as hypothesized and confirm that living in greater proximity to parks is associated with small increases in PA through their visitation. Associations between park proximity to home and PA did not appear to be due to residential self-selection, corroborating previous research (Kaczynski and Mowen 2011).

Interestingly, home neighborhood parks were also associated with non-home neighborhood park PA. This may be an indicator of how parks contribute to active travel for recreational purposes. Home neighborhood park count was positively associated with non-home neighborhood park PA. Having many parks in one's neighborhood may facilitate recreational active travel to other parks beyond the home neighborhood. In this case, multiple parks would function as a "greenway," or a series of linked spaces to walk/run/bicycle through that are protected from the noise and danger of traffic on busy streets. Conversely, home neighborhood park area was negatively associated with non-home neighborhood park PA. Greater acreage of parkland in one's home neighborhood may be more likely to meet one's park activity needs and thus reduce the necessity to travel to parks further from home. To the extent possible, park systems should be designed such that parks are integrated into the urban fabric so they may support active travel to other destinations, including larger parks that can support a range of recreational activities. Because neither home neighborhood park count nor area was associated with total PA, the two measures of home neighborhood park proximity may be more informative for where rather than how much people are likely to be active.

Progressively controlling for BE covariates illustrated how parks are an integral yet nuanced component of neighborhoods that support active living. For the exposure of home neighborhood park count, failure to control for the BE resulted in spurious small yet significant positive relationship with other PA, likely because count of parks is a proxy for neighborhoods that supports PA through dense street networks and many destinations that can be reached by active travel modes (including parks). For the exposure of home neighborhood park area, failure to control for the BE resulted in a spurious negative relationship with other PA, likely because park area is a proxy for neighborhoods with a sparse street network and fewer other destinations where most daily activities must be reached by car (Figure 1-3). While neighborhood parks do contribute to PA, efforts to modify the BE to support PA should consider parks as one piece of a balanced overall neighborhood environment with a variety of accessible utilitarian and recreational destinations.

We explored how household dynamics interacted with home neighborhood parks proximity to affect PA. The number of home neighborhood parks had a stronger association with home neighborhood park PA among people who lived with children or dogs – household members who may demand to be taken to the park. This stronger association, however, was only observed for the exposure of home neighborhood park count, not area. This is perhaps because multiple parks better support dog walks through the neighborhood. Or there could be a better chance of having at least one suitable off-leash or playground facility in the home neighborhood when there are many parks. New parks may have the greatest impact on PA in neighborhoods with many dogs or children.

Parks may also affect PA differently at different neighborhood scales. Our main analysis used a conservative 10-minute walk (833m) to define the home neighborhood. When the definition was expanded to a 30-minute walk (2.5km), park count had little effect on PA; but park area was related to both home neighborhood park PA and other PA, which resulted in a cumulative effect on total PA. The association between 2.5km home neighborhood park area and other PA could be due to residential self-selection, where adults who lead more active lifestyles preferentially choose to live close—but not too close—to larger areas of parkland. However, this explanation seems unlikely after controlling for many other sociodemographic and BE variables. Furthermore, the results remained after controlling for importance of parks for neighborhood choice (results not shown) and studies of residential property values show that the premium of a large and heavily used nearby park reaches an apex a couple of blocks from the park and extends up to 3000ft from the park (Crompton 2001). Further research will be necessary to understand why neighborhood park area is associated with PA unrelated to park use when a larger neighborhood definition is used. Detailed comparisons of activity patterns and PA locations between those with high and low park acreage within the 2.5km home neighborhood buffer may help explain the results, but are beyond the scope of the current analysis. Natural experiments of changes in PA activity patterns after parks are introduced or closed would provide an even stronger evidence base for how parks influence PA.

This study used comprehensive and objective measures of park-related PA to thoroughly describe how home neighborhood parks are associated with PA. It provides a high level of detail, but may lack generalizability because it was conducted among a sample that was urban, mostly white, well-educated, and well served by neighborhood parks. Accelerometers were used to measure PA, which fails to capture bicycling and some other types of physical activity (e.g., swimming). This study did also not account for the characteristics of parks in the home neighborhood that may influence use (Bedimo-Rung, Gustat et al. 2006, Rundle, Quinn et al. 2013). In particular, park amenities/facilities, cleanliness, disorder, and safety were not measured. However, neighborhood wealth was controlled for in analyses and may serve as a proxy for these characteristics. Park data were only collected at baseline and may have changed at first and second follow-up if parks were built or closed over the 5-year study. This was probably minimal because parks are infrequently built or closed. Finally, the definition of park used in this study may not capture all park-like settings, such as privately owned public spaces or schools with open use policies.

However, the definition is likely most relevant to park agencies that must make decisions on how to invest public funds in the places they manage.

Conclusion

Home neighborhood park count and area were both positively associated with home neighborhood park PA. The count of home neighborhood parks was positively associated with non-home neighborhood park PA, while the area of home neighborhood parks was negatively associated with non-home neighborhood park PA. Because park PA accounted for a small proportion of total PA and home neighborhood park proximity measures were not associated with other PA, home neighborhood park proximity measures were not associated with total PA. Opposing directions of associations for park count and area with non-home neighborhood park PA may reflect how the spatial structure of the park system can influence active travel for recreational purposes and the location of park PA. Associations between home neighborhood parks and PA also varied by some aspects of household composition and the definition of home neighborhood. Park system managers and planners should consider these factors when designing park systems to optimally support PA.

Tables and Figures

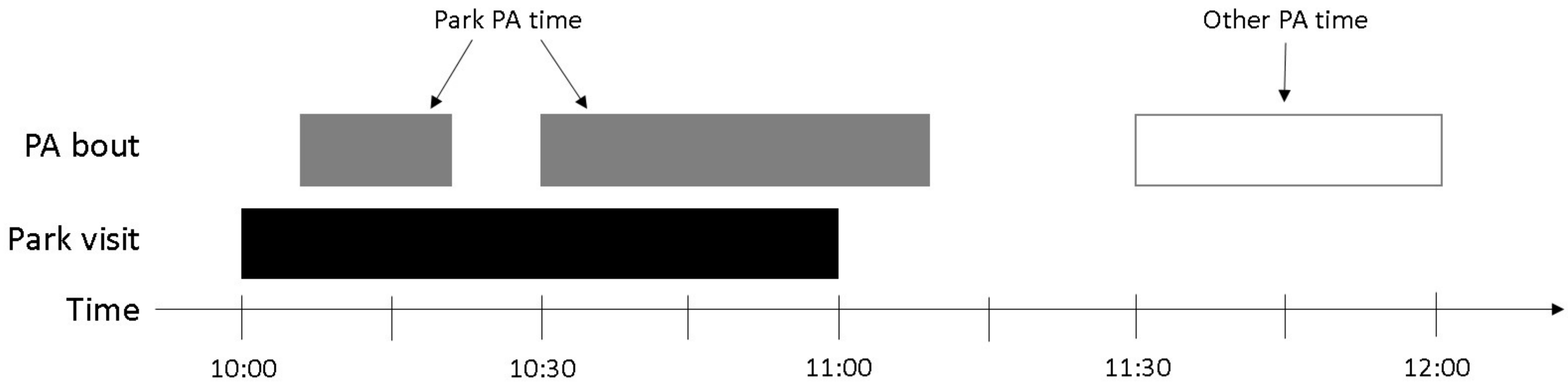


Figure 1-1: Timeline illustrating classification of PA bout time as park (grey block) or other (white block) depending on any temporal overlap with a park visit (black block)

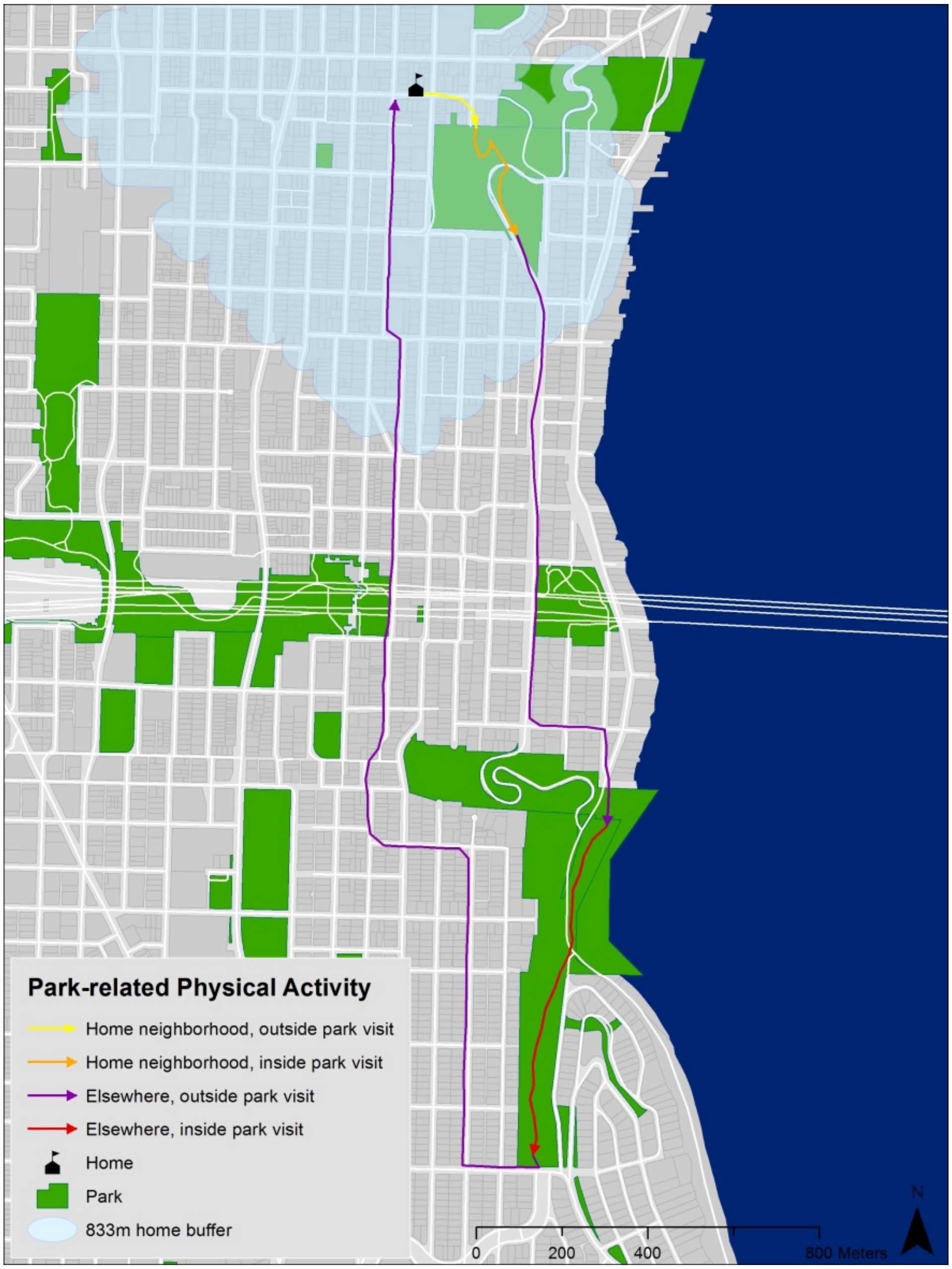
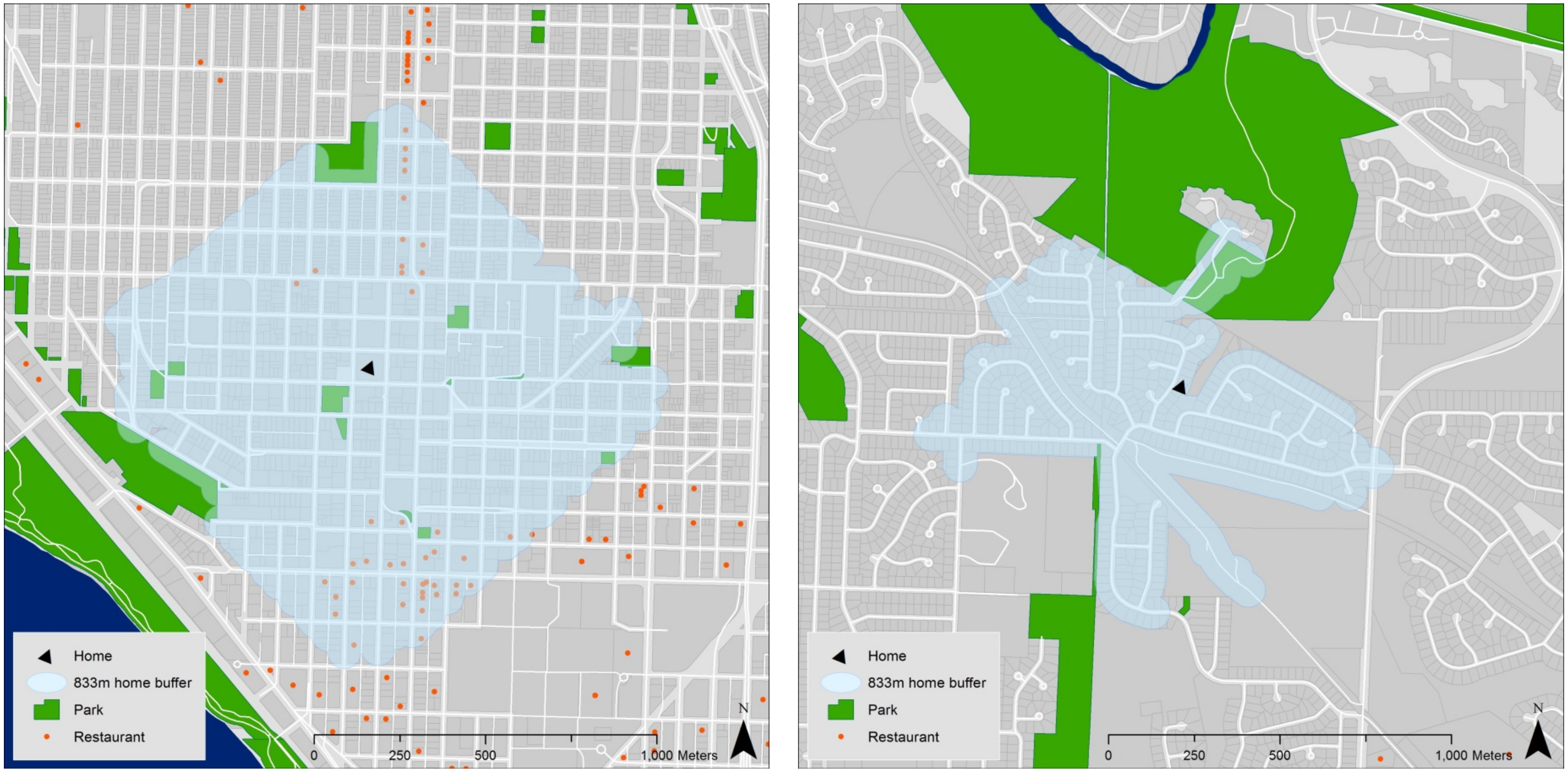


Figure 1-2: Classification of park physical activity bout that extends through two park visits. The yellow and orange portions are classified as home neighborhood park PA because they occur prior to or during a home neighborhood park visit; the purple and red portions are non-home neighborhood park PA because they occur prior to, during, or after a non-home neighborhood park visit that does not precede another park visit.



Panel A: Home neighborhood with a high count (n= 13) but low area (26.9 acres) of parks

Panel B: Home neighborhood with a low count (n= 2) but high area (1,066.9 acres) of parks

Figure 1-3: Contrast of home neighborhoods with high count vs. area of parks. Compared to neighborhoods with a few large parks (panel B), neighborhoods with many small parks (panel A) may have many other routine utilitarian walking destinations (e.g., restaurants) and an extensive street network that provides options for walking routes.

Table 1-1: Sample characteristics by observation period

Domain	Variable	Baseline (n=582) mean (SD) / n (%)	First follow-up (n=434) mean (SD) / n (%)	Second follow-up (n=379) mean (SD) / n (%)
observation	Valid days during observation period	6.2 (1.7)	6.2 (1.7)	6.5 (1.3)
	Wear time (mean daily hours)	14.2 (1.6)	14.1 (1.7)	14.1 (1.5)
Sociodemographics	Age, <45	211 (36%)	146 (34%)	103 (27%)
	45-64	292 (50%)	210 (48%)	193 (51%)
	≥65	79 (14%)	78 (18%)	83 (22%)
	Gender, male	223 (38%)	161 (37%)	133 (35%)
	Race/ethnicity, non-Hispanic white	464 (80%)	351 (81%)	300 (79%)
	Education, no college degree	169 (29%)	107 (25%)	85 (22%)
	4-year degree	216 (37%)	154 (35%)	144 (38%)
	graduate degree	197 (34%)	173 (40%)	150 (40%)
	Household income, <$30k	109 (19%)	82 (19%)	58 (15%)
	$30-$60k	160 (27%)	118 (27%)	100 (26%)
	$60-$90k	138 (24%)	94 (22%)	83 (22%)
	>$90k	175 (30%)	140 (32%)	138 (36%)
	Children >18 years	140 (24%)	93 (21%)	91 (24%)
	Body Mass Index, <25	282 (48%)	208 (48%)	187 (49%)
	25-29.9	179 (31%)	129 (30%)	118 (31%)
	≥30	121 (21%)	97 (22%)	74 (20%)
	Car:adult ratio	0.8 (0.5)	0.8 (0.5)	0.9 (0.4)
	Single family home	285 (49%)	223 (51%)	213 (56%)
	Importance of parks for n'hood selection, Not	142 (24%)	NA	NA
	Somewhat	195 (34%)	NA	NA
	Very	243 (42%)	NA	NA
	Household dog present	NA	84 (20%)	73 (19%)
Home n'hood BE (833m buffer)	Residential units	4164.7 (3521.1)	4265.2 (3613.9)	4254.3 (3798.1)
	Employment improvement area (1000 sq ft)	4566.9 (8307.3)	4761.9 (8646.3)	3819.2 (7764.5)
	Restaurant count	64.9 (95.4)	65.9 (96.8)	54.9 (85.6)
	Intersection count	127.3 (61.5)	128.4 (62.4)	122.8 (60.9)

Domain	Variable	Baseline (n=582) mean (SD) / n (%)	First follow-up (n=434) mean (SD) / n (%)	Second follow-up (n=379) mean (SD) / n (%)
	Sidewalk length (km)	16.4 (9.2)	16.9 (9.1)	16.1 (9.2)
	Buffer size (acres)	304.4 (75.6)	306.9 (76.6)	303.9 (76.1)
	Mean wealth percentile	34.7 (12.9)	36.3 (13.3)	37.4 (13.4)
	Park count	4.9 (2.9)	4.9 (2.8)	4.7 (2.9)
	Park area (acres)	56.9 (84.8)	60.3 (95)	61.4 (95.4)
Park visits	Home n'hood park visits (per week)	0.4 (1.2)	0.4 (1.4)	0.6 (2.1)
	Non-home n'hood park visits (per week)	1.1 (2.0)	1.0 (1.9)	1.4 (2.5)
Mean daily PA	Home n'hood park PA (minutes)	1.2 (4.3)	1.1 (4.3)	1.4 (5.4)
	Non-home n'hood park PA (minutes)	3.4 (7.9)	3.3 (7.8)	3.5 (8)
	Other PA (minutes)	38.0 (30.8)	33.9 (25.4)	33.4 (25.7)
	Total PA (minutes)	42.7 (32.9)	38.3 (28.1)	38.3 (28.5)

Table 1-2: mixed-effects negative binomial regression model results (n=634 individuals, 1395 observation periods)

		model 1*		model 2**		model 3***	
exposure	**outcome**	**IRR (95% CI)**	**p value**	**IRR (95% CI)**	**p value**	**IRR (95% CI)**	**p value**
park count	Home n'hood park PA (minutes)	1.07 (1.00, 1.15)	0.056	1.08 (1.00, 1.16)	0.042	1.09 (1.00, 1.18)	0.039
	Non-home n'hood park PA (minutes)	1.04 (1.00, 1.07)	0.025	1.03 (1.00, 1.07)	0.055	1.05 (1.01, 1.10)	0.020
	Other PA (minutes)	1.05 (1.03, 1.06)	<0.001	1.02 (1.01, 1.04)	0.002	1.01 (0.99, 1.03)	0.599
	Total PA (minutes)	1.05 (1.03, 1.07)	<0.001	1.03 (1.01, 1.04)	0.001	1.01 (0.99, 1.03)	0.348
park acres (log-transformed)	Home n'hood park PA (minutes)	1.63 (1.45, 1.84)	<0.001	1.66 (1.43, 1.93)	<0.001	1.54 (1.34, 1.77)	<0.001
	Non-home n'hood park PA (minutes)	0.98 (0.92, 1.05)	0.621	0.94 (0.88, 1.00)	0.057	0.93 (0.86, 1.00)	0.045
	Other PA (minutes)	0.98 (0.95, 1.01)	0.171	0.97 (0.94, 1.00)	0.023	0.98 (0.95, 1.01)	0.228
	Total PA (minutes)	1.00 (0.96, 1.03)	0.860	0.98 (0.95, 1.01)	0.210	0.99 (0.96, 1.03)	0.614

* Model 1 includes only exposure and count of observation days

** Model 2 includes model 1 variables plus sociodemographic variables of age, gender, race/ethnicity, education, income, children in the household, weight status, and car-to-adult ratio

*** Model 3 includes model 2 variables plus BE variables of single family home, residential units, employment square feet, restaurant count, intersection count, sidewalk length, 833m street network buffer area, and neighborhood wealth

Appendix A: Exploratory Analyses

Table 1-3: Baseline characteristics of those excluded due to no parks in the home neighborhood (833m street network buffer) compared to the analytic sample with ≥1 park.

Domain	Variable	Category	No parks (n=23) mean (SD) / n (%)	≥1 park (n=582) mean (SD) / n (%)	p value
observation	Valid days		6.3 (1.5)	6.2 (1.7)	0.829
	Mean daily wear hours		13.7 (1.3)	14.2 (1.6)	0.091
sociodemographics	Age	<45	4 (17%)	211 (36%)	0.146
		45-64	16 (70%)	292 (50%)	
		≥65	3 (13%)	79 (14%)	
	Gender	Male	6 (26%)	223 (38%)	0.236
	Race/ethnicity	non-Hispanic white	20 (87%)	464 (80%)	0.395
	Education	no college degree	8 (35%)	184 (29%)	0.715
		4-year degree	9 (39%)	228 (37%)	
		graduate degree	6 (26%)	212 (34%)	
	Household income	<$30k	2 (9%)	109 (19%)	0.607
		$30-$60k	8 (35%)	160 (27%)	
		$60-$90k	5 (22%)	138 (24%)	
		>$90k	8 (35%)	175 (30%)	
	Children >18years		6 (26%)	140 (24%)	0.823
	Body Mass Index	<25	12 (52%)	282 (48%)	0.622
		25-30	5 (22%)	179 (31%)	
		≥30	6 (26%)	121 (21%)	
	Car:adult ratio		1.1 (0.5)	0.8 (0.5)	0.050
	Single family home		15 (65%)	285 (49%)	0.126
	Importance of parks for n'hood selection	Not	8 (36%)	142 (24%)	0.181
		Somewhat	9 (41%)	195 (34%)	
		Very	5 (23%)	243 (42%)	
home n'hood BE	Residential units		1161.6 (747.2)	4164.7 (3521.1)	<0.001
	Employment improvement area (1000 sq ft)		687.7 (675.8)	4566.9 (8307.3)	<0.001
	Restaurant count		7.8 (10.8)	64.9 (95.4)	<0.001
	Intersection count		48 (24.2)	127.3 (61.5)	<0.001
	Sidewalk length (km)		2.1 (2.2)	16.4 (9.2)	<0.001
	Buffer size (acres)		199.1 (87.5)	304.4 (75.6)	<0.001
	Mean wealth percentile		34.4 (15.8)	34.7 (12.9)	0.936
Mean daily PA	Park-related PA (minutes)		2.6 (6.7)	4.7 (9.5)	0.156
	PA unrelated to parks (minutes)		18.6 (15.2)	38 (30.8)	<0.001
	Total PA (minutes)		21.2 (17.5)	42.7 (32.9)	<0.001

Table 1-4: Comparison of Poisson and negative binomial model fit

		Poisson		Negative binomial	
Exposure	**Outcome**	**AIC**	**BIC**	**AIC**	**BIC**
Park count	Home n'hood park PA (minutes)	3664.0	3691.2	2643.8	2676.4
	Non-home n'hood park PA (minutes)	8795.0	8822.1	5578.7	5611.3
	Other PA (minutes)	19908.0	19935.2	15081.2	15113.8
	Total PA (minutes)	20426.4	20453.6	15467.9	15500.55
Park acres (log transformed)	Home n'hood park PA (minutes)	3587.6	3614.6	2581.3	2613.6
	Non-home n'hood park PA (minutes)	8497.9	8524.9	5392.7	5419.7
	Other PA (minutes)	19192.4	19219.4	14586.0	14618.4
	Total PA (minutes)	19701.1	19728.1	14965.1	14997.5

Table 1-5: Model 3 results controlling for residential selection among those who did not move from baseline compared to Model 3 results among those who did not move from baseline (n=602 individuals, 1301 observation periods)

		Model 3		model 3 + residential selection	
exposure	**outcome**	**IRR (95% CI)**	**p value**	**IRR (95% CI)**	**p value**
Park count	Home n'hood park PA (minutes)	1.07 (0.98, 1.16)	0.155	1.07 (0.98, 1.16)	0.152
	Non-home n'hood park PA (minutes)	1.04 (0.99, 1.08)	0.108	1.04 (0.99, 1.08)	0.119
	Other PA (minutes)	1.00 (0.98, 1.03)	0.689	1.01 (0.99, 1.03)	0.528
	Total PA (minutes)	1.01 (0.99, 1.03)	0.558	1.01 (0.99, 1.03)	0.408
Park acres (log transformed)	Home n'hood park PA (minutes)	1.51 (1.31, 1.74)	<0.001	1.50 (1.30, 1.73)	<0.001
	Non-home n'hood park PA (minutes)	0.92 (0.85, 1.00)	0.040	0.92 (0.85, 0.99)	0.030
	Other PA (minutes)	0.96 (0.92, 1.00)	0.026	0.96 (0.92, 0.99)	0.026
	Total PA (minutes)	0.97 (0.93, 1.00)	0.080	0.97 (0.93, 1.00)	0.074

Table 1-6: Model 3 results by presence of children aged ≤18 years in household (none vs. any), plus p values of exposure by household children interaction terms in combined sample models.

exposure	Outcome (minutes)	No kid(s) (n=510 individuals, 1071 observation periods) IRR (95% CI)	No kid(s) p value	Kid(s) present (n = 160 individuals, 324 observation periods) IRR (95% CI)	Kid(s) present p value	interaction model (n=670 individuals, 1395 observation periods) interaction p value
park count	Home n'hood park PA	1.05 (0.98, 1.14)	0.185	1.31 (1.17, 1.48)	<0.001	0.154
	Non-home n'hood park PA	1.07 (1.02, 1.13)	0.006	1.03 (0.94, 1.12)	0.523	0.008
	Other PA	1.01 (0.98, 1.03)	0.524	1.02 (0.98, 1.06)	0.400	0.483
	Total PA	1.01 (0.99, 1.04)	0.278	1.02 (0.98, 1.07)	0.279	0.185
park acres (log-transformed)	Home n'hood park PA	1.74 (1.47, 2.06)	<0.001	1.55 (1.02, 2.34)	0.038	0.032
	Non-home n'hood park PA	0.95 (0.87, 1.04)	0.314	0.89 (0.78, 1.01)	0.077	0.165
	Other PA	0.99 (0.95, 1.02)	0.461	0.96 (0.90, 1.03)	0.275	0.600
	Total PA	1.01 (0.97, 1.05)	0.756	0.94 (0.88, 1.01)	0.092	0.100

Table 1-7: Model 3 results by presence of dog in household (none vs. any), plus p values of exposure by household dog ownership interaction terms in combined sample models.

		No dog(s) (n=416 individuals, 645 observation periods)		Dog(s) present (n = 102 individuals, 157 observation periods)		interaction model (n=518 individuals, 802 observation periods)
exposure	**outcome**	**IRR (95% CI)**	**p value**	**IRR (95% CI)**	**p value**	**interaction p value**
park count	Home n'hood park PA (minutes)	0.99 (0.88, 1.10)	0.802	2.04 (1.41, 2.97)	<0.001	<0.001
	Non-home n'hood park PA (minutes)	1.04 (0.97, 1.11)	0.235	1.11 (0.98, 1.24)	0.091	0.144
	Other PA (minutes)	0.99 (0.96, 1.02)	0.568	1.03 (0.99, 1.08)	0.163	0.516
	Total PA (minutes)	0.99 (0.97, 1.02)	0.695	1.05 (1.00, 1.10)	0.046	0.433
park acres (log-transformed)	Home n'hood park PA (minutes)	1.63 (1.31, 2.02)	<0.001	1.63 (0.96, 2.75)	0.069	0.576
	Non-home n'hood park PA (minutes)	1.01 (0.90, 1.13)	0.877	0.95 (0.76, 1.19)	0.652	0.837
	Other PA (minutes)	1.00 (0.95, 1.05)	0.921	0.92 (0.85, 1.00)	0.044	0.346
	Total PA (minutes)	1.02 (0.97, 1.07)	0.437	0.92 (0.85, 1.00)	0.054	0.324

Table 1-8: Sample characteristics based on 2500m home neighborhood buffer. Park exposure and PA outcome measures only.

Domain	Variable	Baseline (n=610) Mean (SD) / n (%)	First follow-up (n=460) Mean (SD) / n (%)	Second follow-up (n=399) Mean (SD) / n (%)
Park proximity	Park count	30.6 (17.9)	31.1 (18.0)	29.4 (17.5)
	Park area (acres)	325.4 (236.4)	339.8 (251.0)	345.8 (256.6)
Mean daily PA	Home n'hood park PA (minutes)	2.0 (5.7)	1.7 (5.2)	2.3 (6.9)
	Non-home n'hood park PA (minutes)	2.6 (7.5)	2.6 (7.6)	2.4 (6.7)
	Other PA (minutes)	37.5 (30.7)	33.5 (26.0)	33.0 (25.5)
	Total PA (minutes)	42.1 (32.7)	37.8 (28.6)	37.8 (28.1)

Table 1-9: Results based on 2500m home neighborhood buffer. Mixed-effects negative binomial regression models (n=1469 observation periods).

		model 1		model 2		model 3	
exposure	Outcome (minutes)	IRR (95% CI)	p value	IRR (95% CI)	p value	IRR (95% CI)	p value
park count	Home n'hood park PA	1.01 (1.00, 1.01)	0.038	1.01 (1.00, 1.02)	0.030	1.01 (0.99, 1.03)	0.270
	Non-home n'hood park PA	1.00 (1.00, 1.01)	0.424	1.00 (1.00, 1.01)	0.154	1.03 (1.01, 1.05)	0.001
	Other PA	1.01 (1.01, 1.01)	<0.001	1.01 (1.00, 1.01)	<0.001	1.00 (0.99, 1.01)	0.617
	Total PA	1.01 (1.01, 1.01)	<0.001	1.01 (1.00, 1.01)	<0.001	1.00 (0.99, 1.01)	0.950
park acres (log-transformed)	Home n'hood park PA	1.80 (1.49, 2.19)	<0.001	1.72 (1.41, 2.09)	<0.001	1.57 (1.22, 2.03)	<0.001
	Non-home n'hood park PA	1.01 (0.86, 1.19)	0.871	0.92 (0.78, 1.08)	0.306	0.99 (0.80, 1.23)	0.916
	Other PA	1.10 (1.03, 1.18)	0.008	1.03 (0.96, 1.10)	0.434	1.12 (1.02, 1.22)	0.013
	Total PA	1.14 (1.06, 1.22)	<0.001	1.05 (0.99, 1.12)	0.122	1.14 (1.04, 1.24)	0.004

Appendix B: Neighborhood BE variable measurement details

Nine BE covariates were measured under four domains commonly used in active living research and for which secondary GIS data were available: Development density, destinations, transportation systems, and economic environment (Stewart, Carlos et al. 2016).

Density characterizes the intensity of human activity that corresponds to a primary land use. It is closely related to other built environment constructs such as land use mix and street network design (Ewing 1995, Cervero and Kockelman 1997, Rodriguez, Evenson et al. 2009, Frank, Sallis et al. 2010). Density variables included the number of residential units and the square footage of improvements (i.e., buildings) used for employment. The number of residential units was used as a proxy for the intensity of domestic activity. All residential land uses, including multi-family dwellings such as apartments, condominiums, and mixed-use buildings were included in the count of residential units. The square footage of buildings used for employment was used as a proxy for the intensity of work-related activity. Employment land uses include commercial, industrial, governmental, and all other places where people work regularly outside the home. Data were derived from the King County Assessor's parcel database for the years 2008, 2010, and 2013 to correspond with baseline and first and second follow-up.

Destinations are specific travel "attractors" that may also act as environmental stimuli. They fulfill needs for daily living, such as shopping and socializing, while also affecting sights, sounds, smells, and general environmental cognition (Cerin, Leslie et al. 2007, Moudon, Lee et al. 2007, McCormack, Giles-Corti et al. 2008, Rodriguez, Evenson et al. 2009). In this study destinations were captured through the count of restaurants. Restaurants were associated with neighborhood walking for utilitarian purposes in a variety of built environments (Stewart, Vernez Moudon et al. 2016) and serve as an indicator of other retail and entertainment destinations. Restaurant data were derived from geocoded Public Health Seattle-King County food service permits for the years 2008 (baseline) and 2013 (first and second follow-up) (Moudon, Drewnowski et al. 2013).

Transportation systems describe the physical form of the transportation network and opportunities for accessibility and movement (Cervero and Kockelman 1997, Frank, Schmid et al. 2005, Frank, Sallis et al. 2010). In this study, transportation system characteristics were measured as the count of ≥3-way intersections, the length of sidewalks, and the size of the buffer area. Intersection count captures the block size and option for various routes, which may allow for safer or more comfortable travel (Berrigan, Pickle et al. 2010). Intersections were derived from the pedestrian-accessible King County Transportation network. Multiple intersections ≤50 feet apart were dissolved into one intersection to account for spatial representations of the street network that would otherwise lead to an over count of intersections (e.g., two line segments often represented one street divided by a median and would result in two intersections when it met a cross-street) (Design For Health 2012). Sidewalk length was measured as the length of the King County street network centerlines with full sidewalk coverage on both sides of the street (Kang, Scully et al. 2015). Presence of sidewalks along streets was intended to capture the comfort and safety of pedestrian routes to or from the park. Buffer area, when applied to a street network buffer as in this case, is a direct measure of the area accessible by walking 10-minutes in any direction of an individual's home. It reflects the completeness of the street network and, when included as a model covariate, enables all other BE coefficients to be interpreted as gross densities.

Economic environment variables capture the wealth and value of the built and natural environment and serve as a proxy for the wealth or deprivation of neighborhood residents (Krieger, Williams et al. 1997, Moudon, Cook et al. 2011). Economic environment was measured as the average King County percentile of the assessed value of residential units (land + improvement). Data were derived from the King County Assessor's parcel database for the years 2008, 2010, and 2013 to correspond with baseline and first and second follow-up. Residential wealth is conceptualized to be a relative measure, and thus percentiles of residential assessed values were used to account for the secular decline in property values during the study period (King County median assessed residential unit values declined from $309,727 in 2008 to $262,996 in 2013).

Aim 2A: Are park facilities associated with use of parks for physical activity?

Abstract

Prior research has found a positive relationship between the variety of park facilities and park-based physical activity (PA), but has not provided an estimate of the effect that additional different PA facilities have on whether an individual is active during a park visit. Using objectively measured PA and comprehensively measured park visit data among an urban community-dwelling sample of 699 adults in King County, Washington, we compared the variety of PA facilities in parks visited where an individual was active to PA facilities in parks where the same individual was comparatively sedentary. Multivariable conditional relative risk regression was used to estimate the within-person effect of PA-related park facilities on the occurrence of PA while also controlling for other park features, park neighborhood features, and park visit characteristics. Compared to the 474 study participants who did not make both active and sedentary visits, the 225 adults who made both active and sedentary visits were younger, more highly educated, more likely to have children in the household, and considered parks to be more important for residential location selection. Among these 225 adults, each additional different PA facility at a park was associated with a 7% (95% CI = 2%, 11%; p =0.003) increased probability of being active during the visit. Adding additional different PA facilities to a park would appear to have a moderate effect on whether an individual is active during a park visit, which could translate into large community health impacts when applied to all visitors to a park.

Introduction

Parks fulfill many public health functions, one of which is to provide low- or no-cost places for physical activity (PA) (Bedimo-Rung, Mowen et al. 2005). Experts have called for developing and enhancing parks as a way to increase population levels of PA and combat the obesity epidemic (US National Physical Activity Plan Coordinating Committee 2010). Yet public parks include a diverse range of places and features, from urban plazas to undeveloped greenbelts, from sports fields and arenas to beaches, and everything in-between (Zanon, Hall et al. 2014). If park planners are to heed the call to develop parks that support PA, they may benefit from evidence on the characteristics of parks that contribute to PA.

Direct observations of park activity show that greater PA levels occur in parks with programming (Floyd, Bocarro et al. 2011, Cohen, Han et al. 2016) and onsite promotions (Cohen, Han et al. 2016) as well as parks located in more walkable neighborhoods and residents of higher socioeconomic status (Van Dyck, Sallis et al. 2013, Baran, Smith et al. 2014, Cohen, Han et al. 2016). These park and neighborhood characteristics can serve as points of intervention to increase park-based PA. Adding park facilities that directly support PA (PA facilities) is another, perhaps more straightforward, strategy to increase park-based PA. A greater variety of PA facilities in a park would increase the chances that each visitor could find at least one, if not many, enjoyable activities through which to obtain PA.

Studies comparing direct observations of active park visitors to sedentary park visitors found that active park visitors were more likely to be in park areas with PA facilities, such as courts, paths, and playgrounds (Shores and West 2008, Floyd, Bocarro et al. 2011). Additionally, installing or upgrading park PA facilities often (Tester and Baker 2009, Cohen, Marsh et al. 2012, Veitch, Ball et al. 2012), but not always (Cohen, Golinelli et al. 2009), led to increases in observed levels of PA. These studies suggest that people are more active in park settings with PA facilities, and that there may be a latent demand for PA facilities. Direct observation of park users, however, cannot provide insight into how PA facilities may change an individual's behavior in a park. Outdoor recreation behaviors are strongly associated with individual characteristics such as age, race, gender, and socio-economic status (Lee, Scott et al. 2001). Some individuals may always be active in parks while others may always be sedentary. If this were the case, additional PA facilities would only benefit those who are already active and likely at low risk for overweight and obesity.

To date, studies using individual-level measures of park-based PA also provide only few insights into how park PA facilities affect an individual's PA behaviors. The presence of certain facilities and amenities in nearby parks were associated with home neighborhood park-based PA (Giles-Corti, Broomhall et al. 2005, Kaczynski and Havitz 2009, Sugiyama, Francis et al. 2010, Kaczynski, Besenyi et al. 2014). But these studies are of limited insight since the facilities measured in home neighborhood parks may not necessarily match the specific parks that were actually used for PA. Among 1,305 adults in Odense, Denmark, the number of PA facilities in the closest park to one's home was positively associated with the likelihood of PA in the closest park occurring at least once a week, but the association did not remain after adjusting for park size (Schipperijn, Bentsen et al. 2013). Kaczynski et al. (2008) examined individual-level data but using the park as the unit of analysis by testing the association between the number of park PA features and whether a park was used for PA by any of 380 adult neighborhood residents as recorded in weeklong activity diaries. The odds of *any* participant using a park for PA doubled for each additional PA facility, an effect that is difficult to interpret in terms of changes to an individual participant's behavior because the outcome is aggregated across all study participants. This small body of literature suggests that a greater variety of park facilities will result in greater PA among park visitors, but fails to provide a robust estimate of the effect they have on an individual's behavior due to a lack of specificity between the park facilities and location of PA; a focus on only the park that was nearest to home; or an aggregation of individual-level activity to the park level. Additionally, the evidence supplied by these studies is weakened due to reliance on self-reported park use and physical activity data, both of which are notoriously subject to recall bias (Sallis and Saelens 2000, Stewart, Moudon et al. 2016).

In this study we use objectively measured activity data to provide a robust estimate of the association between the facilities in a park and an individual's behavior in the park, specifically whether or not an individual uses a park for PA. We treat individual participants as their own controls and compare PA facilities in parks that an individual visited while active to parks the same individual visited while sedentary, regardless of the proximity to home. We hypothesize that, after controlling for park and park neighborhood characteristics, a greater variety of PA facilities in a park will be associated with an increased likelihood of an individual being active during a visit. A greater number of different PA facilities translates into a greater chance that a park supports at least one activity that a visitor would desire to participate in.

Methods

Sample population

This study presents a repeated cross-sectional analysis of data from the Travel Assessment and Community (TRAC) project. The TRAC project was a longitudinal study of travel and activity in relation to light rail implementation in King County, Washington. The sample frame included King County residents in areas proximal (<1 mile) or distal (>1 mile) from planned light rail stations, but with otherwise similar home neighborhood built and (initially the same) transportation environments (Moudon, Saelens et al. 2009). Parcel-based sampling was used to identify households located in the sample frame (Lee, Moudon et al. 2006). Households were contacted by telephone between July 2008 and July 2009 and participants were recruited if they were aged 18 or older, able to complete a travel diary and survey in English, and able to walk unassisted for ≥10 minutes. The Seattle Children's Hospital IRB approved the study. A total of 699 enrolled participants completed baseline data collection, 584 and 532 of whom also completed first and second follow-up data collection, respectively. Follow-up data collection occurred 2 and 4 years after baseline. At each time participants completed a survey and provided data on their activities for a one-week period. Follow-up data collection was planned for the same time of year for each participant. Data from all waves were used for analysis to capture usual park-related behavior.

Data collection and measures

Activity

A detailed description of the activity data collection and processing is available elsewhere (Kang, Moudon et al. 2013). Briefly, participants were instructed to wear an accelerometer (GT1M; ActiGraph LLC, Fort Walton Beach, FL, at baseline and GT3X, ActiGraph LLC, Fort Walton Beach, FL, at first and second follow-up), carry a GPS device (DG-100, GlobalSat, Taipei, Taiwan, at baseline and first follow-up and BT-1000XT GPS data logger, Qstarz, Taipei, Taiwan, at second follow-up), and complete a place-based paper travel diary for a one-week period at each assessment time point. Data from the three instruments for each participant were integrated by time matching GPS and travel diary locations to each 30-second accelerometer epoch (Hurvitz, Moudon et al. 2014). In this analysis, observation days were considered valid if they had ≥1 place recorded in the travel diary, ≥3 minutes of GPS data, and an accelerometer wear time of ≥8 hours. Accelerometer periods of ≥20 minutes with continuous zeroes were considered non-wear times (Masse, Fuemmeler et al. 2005).

Parks and park facility exposure measures

Park location and size data were collected from King County and the 39 municipalities located within it in the form of GIS datasets, maps, spreadsheets, city planning documents, and text descriptions in spring 2008. We defined parks as publicly owned, freely accessible, outdoor spaces intended for leisure or recreation and distinct from street right-of-ways. Using this definition, we excluded aquariums, boulevards, golf courses, pools, community centers, boat launches, wilderness areas, cemeteries and similar places unless they were located entirely within a park that did fit our definition. Data not already stored in a GIS format were digitized using editing tools in ArcGIS 9.2 with the aid of tax parcel data and aerial imagery. Park GIS data from each jurisdiction were then combined to create a single dataset that was the aggregate of all input geometries. The combined dataset contained 1,438 discrete parks with unique names.

Park facility and amenity data came from park management databases, inventories, or brochures and were obtained from each jurisdiction. These data were then added to each park record. Facility data were available for 1,080 (75%) of the parks in the GIS database. Facility data for an additional 23 parks visited by participants but with facility data that were not available from the initial round of public agency data collection were developed using supplemental material from public agencies or online resources such as Google maps (Taylor, Fernando et al. 2011). Data were recorded as the presence of 103 different facilities/amenities. Facilities/amenities were classified as PA facilities (e.g., tennis courts, fields), built amenities (e.g., barbeques, bathrooms, parking lots), and natural amenities (e.g., shorelines, greenebelts) (Appendix A, Table 2-4). This classification is similar to that used by in-person park audit instruments such as the Community Park Audit Tool (CPAT) (Kaczynski, Stanis et al. 2012), the Environmental Assessment for Public Recreation Spaces (EAPRS) instrument (Saelens, Frank et al. 2006), and the Public Open Space Tool (POST) (Giles-Corti, Broomhall et al. 2005). For analysis, park-level facilities/amenities were measured as the count of different PA facilities (e.g., 2 tennis courts were counted as 1 facility), the count of different built amenities, and the binary presence of any natural amenities.

Parks were also characterized using GIS measures of size (acres) and mean slope. Sloping terrain within parks may contribute to views, support for or hindrance of PA (e.g., stair climbing), and/or space limitations for building facilities/amenities. Slope data were derived from the U.S. Geological Survey National Elevation Dataset (USGS NED). Elevation data were represented in raster datasets with a cell size of 1/3 arc-second (approximately 10 m), from which mean slope within the park was calculated.

Park visits

Park visits were comprehensively measured using two sources: travel diaries and GPS/GIS data. For each place visited, participants recorded in the travel diary the place name and time of arrival and departure. Travel diary places were reviewed for names matching those of public parks. Each travel diary park visit was linked to a park in the GIS database based on the park name. Matched park names were considered park visits if the duration between the arrival and departure time was ≥3 minutes (Evenson, Wen et al. 2013). Park visits were also sensed from the GPS/GIS data using a method similar to that pioneered by Evenson et al. (2013). Sensed visits consisted of ≥3 minutes of consecutive GPS points in the same GIS park polygon, with a speed <30 km/h and a distance of >50 m from the participant's home and work, while allowing for gaps of ≤45 minutes. If a sensed visit temporally overlapped with a visit recorded in the travel diary, the presumably more precise duration from the GPS data was used.

Active and sedentary park visits

Park visits were classified as active or sedentary based on whether an MVPA bout occurred during the visit. MVPA bouts were defined as time intervals with vertical axis accelerometer counts ≥976 per 30-second epoch for at least 5 minutes, allowing for counts to drop below that threshold for up to 2 minutes during any 7-minute interval. This corresponds with the commonly used adult threshold of 1952 Actigraph activity counts per minute (Gorman, Hanson et al. 2014). For simplicity we used the term "sedentary" to describe park visits during which an MVPA bout did not occur, even though a participant could have performed low-intensity activity during the visit.

Park visit characteristics

Characteristics of the park visit potentially related to both the decision of which park to visit and the occurrence of PA were measured as covariates. These measures included the duration of the visit, quarter of year, day of week (weekend or weekday), time the visit started (before 11am, 11am-3pm, and after 3pm), mean daily temperature (°F), the presence of any precipitation during the day, whether the visit was reported in the travel diary, whether or not the visit was sensed from GPS data, and the network distance from the participant's home to the closest point along the park boundary (closest points were identified using Euclidean distances from home to the park boundary). Climatic measures were date-matched to park visits using conditions reported at Seattle-Tacoma International Airport by the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration).

Park neighborhood built environment characteristics

Built environment (BE) features that could support PA were measured in the neighborhood immediately surrounding each park as covariates. Park neighborhoods were delineated as 400-meter Euclidean buffers from park perimeters, restricted to the land areas on which the parks were located (Figure 2-1). This buffer size was chosen to capture the 2-3 street-block area immediately surrounding each park, which could conceivably draw activity out of the park or to the park and hence confound the effect of park facilities on PA in parks. BE measurements and data sources are detailed in Appendix B. Briefly, BE covariates fell under four domains commonly associated with active living and for which secondary GIS data were available: development density, destinations, transportation systems, and economic environment (Stewart, Carlos et al. 2016). Density variables included net residential density and employment floor-area ratio (FAR), which is a proxy for a pedestrian-oriented site design (Saelens, Sallis et al. 2012). Destination variables included count of restaurants as an indicator of utilitarian destinations and count and acreage of other parks as an indicator of nearby recreational opportunities. Transportation system variables included the count of ≥3-way intersections, the length of sidewalks, and the mean slope of terrain in buffer area. Due to large variations in park neighborhood buffer sizes, destination and transportation variables were standardized by buffer acreage, resulting in density measures (e.g., restaurants per park neighborhood buffer acre). Economic environment was measured as the average King County percentile of the assessed value of residential units (land + improvement).

Socio-demographics

Socio-demographics were collected from the baseline survey and included age, gender, race and ethnicity, highest level of education, annual household income, presence of children under age 18 in the household, and Body Mass Index (BMI). Single family vs. other residence types (apartment, condo, townhouse, other) was included as a proxy for presence of outdoor green space at home as an alternative to the outdoor green space that parks provide. Importance of "closeness to open space (e.g. parks)" as a reason for neighborhood selection was measured on a 5-point Likert scale. Responses were trichotomized as not at all/not important, somewhat important, or important/very important.

Analysis

We used a case-crossover study design (Chaix, Kestens et al. 2016). Each individual served as his/her own control to compare the variety of facilities at parks he/she visited while in an MVPA bout (active visits) versus parks he/she visited while not in an MVPA bout (sedentary visits). This restricted the analytic sample to participants who had both active and sedentary park visits during observation periods. We first describe these participants in socio-demographic terms and compare them with participants who did not visit parks, only had active park visits, or only had sedentary park visits using Chi square tests for statistically significant differences ($P < 0.05$).

Next, among the sample of participants who had both types of park visits (active and sedentary), we compared active and sedentary park visits in terms of park characteristics, park neighborhood characteristics, and visit characteristics. We used t-tests and chi square statistics to test for differences between active and sedentary visits, not accounting for the correlation of visits within individuals.

Finally, we used a conditional relative risk (RR) regression model to control for individual characteristics while estimating the association between the continuous value of the variety of PA facilities in a park and an individual visiting the park for an active versus sedentary visit. Conditional, or fixed-effects, models effectively control for all non-varying characteristics of active and sedentary visits grouped within the same individual (e.g., demographics) (Locascio and Atri 2011). A modified Poisson regression model with robust error variances was used to approximate RR (Zou 2004), which is a more appropriate measure than an odds ratio for common outcomes (Lovasi, Underhill et al. 2012). The RR from this model can be interpreted as the mean within-person change in probability of any MVPA while visiting a park for each additional type of PA facility present in the park. Three additional multivariable conditional RR regression models were developed to progressively control for characteristics that varied between park visits made by the same individual: model one only contained the main exposure of interest (park PA facilities), model two adjusted for other characteristics of the park, model three further adjusted for park neighborhood characteristics, and model four further adjusted for visit characteristics.

Results

A total of 2,451 park visits to 317 unique parks occurred during the three TRAC study observation periods. Of these visits, 1,190 (49%) temporally overlapped with an MVPA bout and were considered active visits; the remaining 1,261 visits during which no MVPA bout occurred were considered sedentary visits. The 2,451 park visits were made by 461 unique individuals, 225 of whom made both active and sedentary visits and thus comprised the analytic sample. Table 2-1 details the comparisons between these 225 individuals and the 238 who did not visit a park, the 141 who only had sedentary visits, and the 95 who only had active visits. Individuals with both types of park visits were younger, more highly educated, more likely to have children in the household, considered parks to be more important for neighborhood selection, and participated in the study for more observation periods than all three other groups. Individuals with both types of visits had higher incomes and were less likely to be obese than those who did not visit parks or who only had sedentary visits, but not those who only had active visits. The four visitation groups did not significantly differ on gender, race/ethnicity, or housing type.

The 225 individuals who made both active and sedentary park visits visited parks an average of 7.9 times across all assessment periods (SD = 6.4, median = 6). These park visits were evenly split between active and sedentary park visits, with an average of 4.0 (SD = 3.9, median = 3) sedentary and 3.9 (SD = 4.0, median = 2) active visits each. Table 2-2 compares characteristics of these active and sedentary park visits without accounting for the correlation of park visit characteristics within individuals. Active visits were at parks with a greater variety of PA facilities, a greater likelihood of having natural amenities, larger acreage, and steeper terrain. The number of built amenities did not differ between active and sedentary visit parks. Active visits occurred at parks in neighborhoods with lower residential densities, fewer restaurants, a greater density of other parks, a greater linear density of sidewalks, greater residential wealth, and steeper terrain. Neighborhoods surrounding visits that were active versus sedentary did not significantly differ in employment development densities, intersection densities, and park land area. Active and sedentary park visits were of similar durations, equally likely to be reported in the travel diary, and equally likely to occur on the weekend. Compared to sedentary visits, active visits occurred more often in the first or third quarters (winter or summer) of the year, on days with precipitation, on cooler days, and before 11:00am. Active park visits also were more likely to be sensed by the GPS device and occur in parks closer to home.

Controlling for individual characteristics through conditional RR regression, each additional different PA facility at a park was associated with a 6% increase in the probability of a visit being active versus sedentary (RR = 1.06; 95% CI = 1.04, 1.09; $p < 0.001$) (Table 2-3, model 1). Controlling for park characteristics resulted in a slightly stronger effect size for the variety of PA facilities (RR = 1.10; 95% CI = 1.06, 1.14; $p < 0.001$), and all other park characteristics excluding park size were also independently associated with the likelihood of an active park visit (Table 2-3, model 2). Further controlling for park neighborhood characteristics slightly attenuated the association between PA facilities and active visits (Table 2-3, model 3). Further controlling for visit characteristics further attenuated the association between PA facilities and active visits, and resulted in an estimate similar to the crude model (RR = 1.07; 95% CI = 1.02, 1.11; $p = 0.003$). In the fully adjusted model, PA facilities, natural amenities, park area density (which can be interpreted as the proportion of the park neighborhood buffer comprised of other parkland), visit duration, GPS-sensed visitation, and distance to home were significantly ($p<0.05$) associated with active visitation (Table 2-3, model 4).

Discussion

We used comprehensive measures of park visitation and objective measures of PA to identify when participants visited public parks and were physically active or not. Using each participant as his/her own control, we observed a robust association between the number of different PA facilities at a park and whether the participant was physically active during a visit. This evidence corroborates prior observed associations between the number of different PA facilities at parks and their use for PA (Kaczynski, Potwarka et al. 2008, Shores and West 2008, Floyd, Bocarro et al. 2011, Baran, Smith et al. 2014, Cohen, Han et al. 2016). This study clearly demonstrates that individuals' PA behavior during park visits varies according to the variety of PA facilities present in the park.

Installing additional different facilities at existing parks could either turn sedentary visits into active visits or induce more active visits. Adding PA facilities to parks appears to be a reasonable intervention to support PA, as a prior study found that installing durable, low-maintenance outdoor exercise equipment at existing parks cost an average of $45,000 and offered a good return on investment in terms of efforts to increase PA (Cohen, Marsh et al. 2012). We explored the possibility of a threshold effect by transforming the PA facility variety variable into quintiles (appendix C, Table 2-5). The largest increase in probability of an active visit occurring were achieved when moving from the first to second quintile of number of different facilities within parks, but the probability of an active visit occurring continued to increase linearly through all quintiles. Adding different facilities to a park that already has many facilities might still contribute to increases in the occurrence of PA.

Our study design controlled for all individual characteristics that may confound the relationship between park PA facilities and active park visitation. Models further controlling for park characteristics, park neighborhood characteristics, and other park visit characteristics resulted in positive associations between natural amenities, closer proximity to home, and additional parkland near the park. These results suggest that parks that provide access to nature, are close to many residences, and are components of larger park systems may also support park-based PA. The presence of natural amenities was the park characteristic most strongly associated with active park visits, possibly because interacting with nature (e.g., exploring a beach) requires some physical exertion or because PA facilities are more inviting when set in a natural environment. In contrast to previous research, park size was not linearly associated with active park visitation (Schipperijn, Bentsen et al. 2013). However, in exploratory models using park size quartiles as a categorical variable (appendix D, Table 2-6), we observed a significant ($p<0.05$) roughly 50% greater probability of an active visit occurring at parks in the 2nd through 4th quartiles (9.3-8294.9 acres) compared to the first quartile (<9.3 acres). It could be that a minimum size of 9 acres – the size of the average neighborhood park (Cohen, Han et al. 2016) – is necessary to support park-based PA (or provide enough space to feature a variety of PA facilities). This association could also be due to our minimum duration of 3 minutes to identify a park visit and the most common form of park-based PA being walking or running (Godbey and Mowen 2010). A jog that passed through a small park in <3 minutes would not be captured in this analysis but a jog through a large park that would likely take more than 3 minutes would. In either case it appears that parks with more facilities, but not necessarily bigger parks, most successfully support the occurrence of PA. A study that focuses on parks that are of similar size but differ substantially in number of facilities would help to further disentangle the issue of park size versus facilities.

Limitations

We analyzed active and sedentary park visits matched within the individual to provide a within-person estimate of the association between PA facilities at active park visitation. This modeling process did not account for the non-independence of park visit observations by the same individual within the same park, which could lead to overstated precision and an artificially narrow confidence interval for model estimates. This analytic approach also limits the generalizability of results to those who were observed to have both active and sedentary park visits, which was a sample biased toward more compliant study participants with more follow up. It is unclear how much observation is necessary to capture “usual” park visitation behavior. Furthermore, only individuals whose active and sedentary visits occurred at parks with a varying variety of PA facilities were informative for estimating the association between PA facilities and active park visitation (Gunasekara, Richardson et al. 2014). Additional PA facilities may not have an influence on individuals who do not visit parks or who are not active during park visits. Yet these types of individuals may benefit the most from no-cost park-based PA, as in the present analysis they had lower incomes (and perhaps access to fewer PA opportunities) and were more likely to be obese than those who were active during park visits. Park programming and marketing campaigns might seek to increase park-based PA among these individuals (Tester and Baker 2009, Cohen, Han et al. 2013).

Our study results may also be biased due to differential reporting of PA facilities across jurisdictions where parks were visited. However, the vast majority (81%, 1432 of 1778 park visits) occurred in parks with facility data provided by a single jurisdiction (Seattle). When analyses were restricted to these parks, we obtained similar unadjusted results (RR = 1.06; 95% CI = 1.03, 1.09; $p<0.001$) but a stronger effect size in the fully adjusted model (RR = 1.11; 95% CI = 1.04, 1.17; $p<0.001$) (Appendix E, Table 2-7). Finally, misclassification of PA facilities may have occurred if PA facilities were installed or closed after park data were collected at baseline. This was probably minimal, as park facilities are relatively fixed and the study period corresponded with a recession during which capital investments in parks was unlikely.

In contrast to prior research using direct observation and park PA levels as the outcome (Van Dyck, Sallis et al. 2013, Baran, Smith et al. 2014, Cohen, Han et al. 2016), our present analysis did not observe an association between park neighborhood wealth and walkability and whether an individual was active or sedentary during a visit. Park neighborhood features likely are more impactful on whether an individual visits a park at all rather than whether that individual is active or sedentary during a visit. Additionally “equitable differences” were found in Seattle parks, whereby facility quality (measured as the condition and cleanliness of the facility) was negatively associated with neighborhood wealth (Engelberg, Conway et al. 2016). In this analysis, any negative association between poorer neighborhood conditions and active park visits may have been confounded by facility quality. Unfortunately due to the extent of the parks involved in this study, park quality as well as social environment conditions of the park, such as safety, could not be explored.

Self-report travel diary data alone was used to identify a small proportion of park visits that were not sensed by the GPS/GIS data. These self-report park visits could be subject to recall and social desirability bias, which is perhaps evidenced by the strong association between the presence of a GPS data and active visitation – compared to self-report, GPS data likely result in a more accurate park visit duration that better corresponds with any accelerometer-measured PA.

Our study included measures of a wide range of park facilities at more than 1,000 parks in King County. However, we cannot identify which specific facilities are most relevant for supporting PA. Trails and paths, children's play areas, tennis courts, athletic fields, water bodies, and basketball courts were most frequently present during active park visits (appendix F, Table 2-8). Yet there is no way of knowing if (or how) these facilities and amenities were actually used for PA. GPS data would need to be overlaid with facility data that are geolocated at their precise location within a park in order to identify which facilities were used for PA. Unfortunately, our facility data were geolocated to the park and not to specific locations within the park. Exploring such microenvironments for PA could be a promising frontier for research using geospatial activity data. In the meantime, direct observation studies at parks may be the best option for identifying which facilities are used most for PA (Cohen, Han et al. 2016).

Conclusion

This study treated each individual as his/her control to test the within-person change in probability of an MVPA bout occurring during a visit to a park based on the variety of PA facilities present in the park. Each additional different PA facility at a park was associated with a 7% increase in the probability of a visit being active versus sedentary (p=0.003) among individuals who were active and sedentary at different parks during the assessment period. Active park visitation was also positively associated with natural amenities, shorter distances to home, and more parkland in the immediate park neighborhood, but not park size. For park system managers, this means that installing more PA facilities, capitalizing on natural features, and integrating individual parks into a larger system of parks could increase park-based PA.

Tables and Figures

Figure 2-1: Illustration of 400m park neighborhood buffer clipped to land area (in grey with water in blue) on which park is located. Park is shown in dark green; park neighborhood buffer is shown in lighter yellow-green

Table 2-1: Individual characteristics of TRAC baseline sample by park visitation

Variable	Category	No visits (n=238)		Sedentary visits only (n=141)		Active visits only (n=95)		Active and sedentary visits (n=225)		P value
		n	%	n	%	n	%	n	%	
Age	<45	62	27%	40	30%	28	33%	100	47%	<0.001
	45-64	126	55%	63	48%	49	57%	93	44%	
	≥65	40	18%	29	22%	9	10%	19	9%	
Gender	Male	91	38%	48	36%	32	36%	81	37%	0.955
Race/ethnicity	non-Hispanic white	180	77%	103	77%	74	84%	177	82%	0.330
Education	no college degree	89	39%	44	34%	23	27%	41	19%	<0.001
	4-year degree	80	23%	50	25%	33	25%	76	26%	
	graduate degree	58	26%	37	28%	30	35%	94	45%	
Household income	<$30k	58	26%	29	23%	13	16%	29	14%	<0.001
	$30-$60k	63	29%	38	30%	23	28%	54	26%	
	$60-$90k	60	27%	26	20%	11	13%	52	25%	
	>$90k	40	18%	35	27%	36	43%	74	35%	
Children <18years in household		33	15%	27	20%	13	15%	77	36%	<0.001
Body Mass Index	<25.0	82	38%	59	48%	49	58%	121	58%	<0.001
	25.0-29.9	68	31%	34	27%	26	31%	62	30%	
	≥30.0	68	31%	31	25%	9	11%	27	13%	
Single family home		101	44%	58	44%	45	52%	113	53%	0.160
Importance of parks for neighborhood selection	Not important	76	33%	37	28%	17	20%	33	16%	<0.001
	Somewhat important	73	32%	51	39%	33	38%	63	30%	
	Very important	78	34%	44	33%	36	42%	115	55%	
Study participation	1 observation period	80	34%	13	10%	12	13%	11	5%	<0.001
	2 observation periods	55	23%	28	21%	20	22%	33	15%	
	3 observation periods	103	43%	94	70%	57	64%	174	80%	

Table 2-2: Characteristics of sedentary and active park visits (n=1,778 visits) among individuals who had both types of visits (n=225 individuals)

		Sedentary visits (n=902)		Active visits (n=876)		
Domain	**Variable**	**n**	**mean (SD) / %**	**n**	**mean (SD) / %**	**p value**
Park	PA facility variety (count)	902	4.7 (2.9)	876	5.6 (2.9)	<0.001
	Built amenity variety (count)	902	2.2 (2.8)	876	2.1 (2.6)	0.816
	Natural amenities (any)	299	33%	396	45%	<0.001
	Park size (acres)	902	85.8 (192.1)	876	126.7 (411.2)	0.008
	Mean slope in park (percentage)	870	4.7 (4.2)	860	5.2 (4.2)	0.042
Park neighborhood	Net residential density (units/residential acre)	902	28.2 (49.3)	876	22.6 (37.8)	0.007
	Employment FAR (employment building acre/ land acre)	902	0.65 (1.23)	876	0.6 (1)	0.363
	Restaurant density (count/buffer acre)	876	0.12 (0.25)	876	0.1 (0.2)	0.023
	Discrete park density (count/buffer acre)	902	0.013 (0.012)	876	0.014 (0.011)	0.009
	Park area density (park acre/buffer acre)	902	0.27 (0.42)	876	0.46 (4.89)	0.238
	Intersection density (count/buffer acre)	876	0.31 (0.14)	876	0.31 (0.12)	0.257
	Sidewalk density (m/buffer acre)	902	39.99 (22.39)	876	43.6 (20.08)	<0.001
	Mean slope in neighborhood (percentage)	902	5.3 (2.3)	876	5.5 (2.2)	0.023
	Wealth (mean percentile of assessed residential unit values)	899	49.4 (19.7)	875	54.6 (18.2)	<0.001
Park visit	Duration (minutes)	902	37.4 (46.5)	876	41.2 (57.1)	0.129
	Quarter, 1st (January – March)	190	21%	236	27%	0.015
	2nd (April – June)	387	43%	330	38%	
	3rd (July – September)	253	28%	251	29%	
	4th (October – December)	72	8%	59	7%	
	Weekend	292	32%	318	36%	0.081
	Start time, <11am	230	25%	301	34%	0.003
	11am-3pm	317	35%	261	30%	
	>3pm	355	39%	314	36%	
	Temperature (°f)	902	55.9 (10.2)	876	54.6 (10.3)	0.006
	Precipitation (any)	413	46%	447	51%	0.027
	Travel diary reported	345	38%	317	36%	0.745
	GPS sensed	789	87%	808	92%	0.001
	Distance from park to home (network Km)	902	7.2 (8.4)	876	4.7 (7.2)	<0.001

Table 2-3: Fixed effects relative risk (RR) regression results for active vs. sedentary park visitation (see Table 2-2 for measurement units of all variables)

	Model 1		Model 2		Model 3		Model 4	
Variable	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**
PA facility variety	1.06 (1.04, 1.09)	<0.001	1.10 (1.06, 1.14)	<0.001	1.09 (1.04, 1.13)	<0.001	1.07 (1.02, 1.11)	0.003
Built amenity variety			0.93 (0.89, 0.96)	<0.001	0.95 (0.91, 0.99)	0.007	0.97 (0.93, 1.01)	0.124
Natural amenities			1.30 (1.13, 1.49)	<0.001	1.21 (1.03, 1.43)	0.020	1.23 (1.05, 1.45)	0.011
Park size			1.00 (1.00, 1.00)	0.884	1.00 (1.00, 1.00)	0.353	1.00 (1.00, 1.00)	0.323
Mean slope in park			1.03 (1.01, 1.05)	0.010	1.02 (1.00, 1.04)	0.070	1.01 (0.99, 1.04)	0.182
Net residential density					1.00 (1.00, 1.01)	0.660	1.00 (0.99, 1.01)	0.834
Employment FAR					1.00 (0.81, 1.23)	0.996	1.00 (0.81, 1.24)	0.976
Restaurant density					0.74 (0.33, 1.66)	0.460	0.78 (0.34, 1.81)	0.570
Discrete park density					45.6 (0.0, 1.1E+7)	0.546	4.1 (0.0, 5.3E+5)	0.816
Park area density					1.03 (1.02, 1.05)	<0.001	1.04 (1.02, 1.06)	<0.001
Intersection density					0.36 (0.07, 1.95)	0.238	0.32 (0.06, 1.81)	0.198
Sidewalk density					1.01 (1.00, 1.02)	0.090	1.01 (1.00, 1.02)	0.187
Mean slope in neighborhood					1.00 (0.96, 1.05)	0.897	1.02 (0.97, 1.07)	0.488
Wealth					1.01 (1.00, 1.01)	0.061	1.00 (1.00, 1.01)	0.266
Duration							1.00 (1.00, 1.01)	<0.001
Quarter, 1st							Reference	
2nd							1.01 (0.76, 1.35)	0.937
3rd							1.02 (0.67, 1.55)	0.933
4th							0.78 (0.52, 1.18)	0.238
Weekend							1.04 (0.91, 1.18)	0.557
Start time, <11am							Reference	
11am-3pm							0.91 (0.78, 1.05)	0.197
>3pm							0.91 (0.77, 1.07)	0.254
Temperature							1.00 (0.98, 1.01)	0.597
Precipitation							1.07 (0.95, 1.21)	0.267
Travel diary reported							1.07 (0.91, 1.25)	0.406
GPS sensed							1.38 (1.09, 1.73)	0.006
Distance from park to home							0.96 (0.94, 0.98)	<0.001

Appendix A: Park facility and amenity classification

Table 2-4: Park facility and amenity classification

Physical activity (PA) facility	Built amenity	Natural amenity
Athletic field	ADA accessible	Arboretum
Ball field	Amphitheater	Beach/waterfront/shoreline access
Baseball field	Arena	Conservancy
Basketball court	Arts/crafts facility	Garden, botanical
Batting cage	Barbeque	Garden, unspecified
BMX course	Bench	Greenbelt
Bocce ball court	Boat launch	Landscaping
Bowling green	Camping	Natural area
Climbing wall/boulders	Chess table	Open space
Cricket Field	Clubhouse	Undeveloped
Dance studio	Community center/activity building	Wetland
Disc golf course	Concessions	Wildlife viewing area
Equestrian facility	Dog off leash area	
Fitness parcourse	Drinking fountain	
Football field	Farm	
Garden, community	Fish ladder/hatchery	
Golf course	Fishing area	
Gym	Fountain/water feature	
Handball court	Gazebo/pergola/pavilion	
Hang gliding field	Historic marker/site	
Hockey court	Indoor facility	
Horseshoe pit	Indoor rental facility	
Lacrosse field	Info kiosk/interpretive exhibit	
Multi-use court	Lights	
Multi-use field	Meeting room	
Open/recreation/grass field	Model airplane flying area	
Pickle ball/badminton court	Parking lot	
Play equipment	Picnic group area	
Pool	Picnic shelter	
Roller hockey court	Picnic table/area	
Running track	Pier	
Skate park	Plaza	
Soccer field	Pool table	
Softball field	Power/electricity	
Spray park	Public art	
Swimming area	Recreation building	
Swing	Reservations	
Tennis court	Restroom	
Tether ball	School	

Physical activity (PA) facility	Built amenity	Natural amenity
Trail	Senior facility	
Trail, bike	Stairs	
Trail, regional	Stretch area	
Velodrome	Viewpoint	
Volleyball court		
Wading pool		
Walking path		
Weight/exercise equipment		
Zip line		

Appendix B: Neighborhood BE variable measurement details

Nine BE covariates were measured under four domains commonly used in active living research and for which secondary GIS data were available: development density, destinations, transportation systems, and economic environment (Stewart, Carlos et al. 2016).

Density characterizes the intensity of human activity that corresponds to a primary land uses, it is closely related to other built environment constructs such as land use mix and street network design (Ewing 1995, Cervero and Kockelman 1997, Rodriguez, Evenson et al. 2009, Frank, Sallis et al. 2010). Density variables included the number of residential units per acre of residential land and the square footage of buildings used for employment per square footage of land used for employment. The number of residential units per acre of residential land is commonly referred to as net residential density. All residential land uses, including multi-family dwellings such as apartments, condominiums, and mixed-use buildings were included in the count of residential units. Employment land uses include commercial, industrial, governmental, and all other places where people work regularly outside the home. The square footage of buildings used for employment per square foot of land or parcels housing the buildings results in the floor-area ratio (FAR). FAR is accepted as a common measure of pedestrian-oriented site design (Saelens, Sallis et al. 2012). Data were derived from the King County Assessor's parcel database for the years 2008, 2010, and 2013 to correspond with baseline and first and second follow-up.

Destinations are specific travel "attractors" that may also act as environmental stimuli. They fulfill needs for daily living, such as shopping and socializing, while also affecting sights, sounds, smells, and general environmental cognition (Cerin, Leslie et al. 2007, Moudon, Lee et al. 2007, McCormack, Giles-Corti et al. 2008, Rodriguez, Evenson et al. 2009). In this study destinations were captured through the count of restaurants and the count and acres of other parks per acre of buffer. Restaurants were associated with neighborhood walking for utilitarian purposes in a variety of built environments (Stewart, Vernez Moudon et al. 2016) and serve as a proxy for other retail and entertainment destinations. Restaurant data were derived from geocoded Public Health Seattle-King County food service permits for the years 2008 (baseline) and 2013 (first and second follow-up) (Moudon, Drewnowski et al. 2013). Nearby parks and park land may act as competing locations for park-based activities.

Transportation systems describe the physical form of the transportation network and opportunities for accessibility and movement (Cervero and Kockelman 1997, Frank, Schmid et al. 2005, Frank, Sallis et al. 2010). In this study, transportation system characteristics were measured as the count of ≥3-way intersections, the length of sidewalks per acre of the buffer area, and the mean slope in buffer area. Intersection density captures the block size and option for various routes, which may allow for safer or more comfortable travel (Berrigan, Pickle et al. 2010). Intersections were derived from the pedestrian-accessible King County Transportation network, which excluded freeways and other roadways where pedestrians are legally not allowed. Multiple intersections ≤50 feet apart were dissolved into one intersection to account for spatial representations of the street network that would otherwise lead to an over count of intersections (e.g., two line segments often represented one street divided by a median and would result in two intersections when it met a cross-street) (Design For Health 2012). Linear sidewalk density was measured as the length of the King County street network with full sidewalk coverage on both sides of the street per acre of the buffer area (Kang, Scully et al. 2015). Presence of sidewalks along streets was intended to capture the comfort and safety of pedestrian routes to or from the park. Slope data were derived from the U.S. Geological Survey National Elevation Dataset (USGS NED). Elevation data were represented in raster datasets with a cell size of 1/3 arc-second (approximately 10 m), from which slope was calculated. Slope captures the exertion required to access the park on foot as well as the potential for visual interest (Lee and Moudon 2006).

Economic environment variables capture the wealth and value of the built and natural environment and serve as a proxy for the wealth or deprivation of neighborhood residents (Krieger, Williams et al. 1997, Moudon, Cook et al. 2011). Economic environment was measured as the average King County percentile of the assessed value of residential units (land + improvement). Data were derived from the King County Assessor's parcel database for the years 2008, 2010, and 2013 to correspond with baseline and first and second follow-up. Residential wealth is conceptualized to be a relative measure, and thus percentiles of residential assessed values were used to account for the secular decline in property values during the study period (King County median assessed residential unit values declined from $309,727 in 2008 to $262,996 in 2013).

Appendix C: Exploration of non-linear trends

Table 2-5: Exploration of non-linear trends for park PA facilities and PA occurrence. Fully adjusted fixed effects relative risk (RR) regression model results for active vs. sedentary park visitation using a categorical variable for park facilities to explore the possibility of non-linear trends.

PA facility variety	RR (95% CI)	p-value
1st quintile (0-2)	Reference	
2nd quintile (3-4)	1.50 (1.10, 2.05)	0.011
3rd quintile (5-6)	1.59 (1.22, 2.07)	0.001
4th quintile (7-8)	1.68 (1.21, 2.32)	0.002
5th quintile (9-13)	1.72 (1.10, 2.68)	0.017

* Model adjusted for park built amenity variety, natural amenity presence, size, slope; park neighborhood net residential density, employment FAR, restaurant density, discrete park density, park area density, intersection density, sidewalk density, slope, wealth; park visit duration, quarter, weekend/weekday, start time, temperature, precipitation, travel diary reporting, GPS sensing, and distance from home.

Appendix D: Exploration of non-linear trends in park size

Table 2-6: Exploration of non-linear trends for park size and PA occurrence. Fixed effects relative risk (RR) regression model results for active vs. sedentary park visitation treating park size as a categorical variable at quartiles.

	Model 1		Model 2		Model 3		Model 4	
Variable	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**
PA facility variety	1.06 (1.04, 1.09)	<0.001	1.08 (1.04, 1.12)	<0.001	1.06 (1.02, 1.11)	0.007	1.05 (1.00, 1.10)	0.054
Built amenity variety			0.92 (0.88, 0.96)	<0.001	0.94 (0.91, 0.98)	0.006	0.97 (0.93, 1.01)	0.116
Natural amenities			1.25 (1.08, 1.45)	0.003	1.21 (1.01, 1.44)	0.035	1.21 (1.01, 1.45)	0.037
Park size, 1st quartile (0.04-9.3 acres)			Reference		Reference		Reference	
2nd quartile (9.4-24.2 acres)			1.42 (1.07, 1.89)	0.015	1.42 (1.05, 1.92)	0.025	1.47 (1.08, 1.98)	0.013
3rd quartile (24.7-125.8 acres)			1.56 (1.19, 2.04)	0.001	1.67 (1.24, 2.25)	0.001	1.57 (1.15, 2.14)	0.005
4th quartile (127.2-8294.9 acres)			1.45 (1.08, 1.95)	0.014	1.50 (1.04, 2.16)	0.031	1.52 (1.01, 2.28)	0.044
Mean slope in park			1.02 (1.00, 1.04)	0.021	1.02 (1.00, 1.04)	0.130	1.01 (0.99, 1.03)	0.215
Net residential density					1.00 (1.00, 1.01)	0.504	1.00 (1.00, 1.01)	0.609
Employment FAR					1.02 (0.83, 1.26)	0.821	1.02 (0.83, 1.25)	0.851
Restaurant density					0.68 (0.30, 1.55)	0.363	0.70 (0.31, 1.63)	0.411
Discrete park density					265.0 (0.0, 1.5E+8)	0.408	7.7 (0.0, 2.6E+6)	0.755
Park area density					1.03 (1.01, 1.05)	<0.001	1.05 (1.02, 1.08)	<0.001
Intersection density					0.51 (0.08, 3.41)	0.484	0.47 (0.07, 3.16)	0.434
Sidewalk density					1.01 (1.00, 1.02)	0.137	1.01 (1.00, 1.02)	0.262
Mean slope in neighborhood					0.99 (0.95, 1.04)	0.689	1.01 (0.96, 1.07)	0.595
Wealth					1.01 (1.00, 1.01)	0.089	1.00 (1.00, 1.01)	0.408
Duration							1.00 (1.00, 1.01)	<0.001
Quarter, 1st							Reference	
2nd							1.03 (0.77, 1.39)	0.829
3rd							1.01 (0.66, 1.54)	0.957
4th							0.77 (0.51, 1.17)	0.222
Weekend							1.03 (0.91, 1.17)	0.623
Start time, <11am								
11am-3pm							0.92 (0.79, 1.07)	0.273
>3pm							0.92 (0.78, 1.07)	0.279

	Model 1		Model 2		Model 3		Model 4	
Variable	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**
Temperature							1.00 (0.98, 1.01)	0.548
Precipitation							1.07 (0.94, 1.21)	0.302
Travel diary reported							1.10 (0.94, 1.29)	0.231
GPS sensed							1.36 (1.08, 1.72)	0.009
Distance from park to home							0.96 (0.95, 0.98)	<0.001

Appendix E: Exploration of bias due to misclassification of exposure measure

Table 2-7: Fixed effects relative risk (RR) regression model results limited to Seattle park visits only (n=1432) for active vs. sedentary park visitation.

	Model 1		Model 2		Model 3		Model 4	
Variable	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**
PA facility variety	1.06 (1.03, 1.09)	<0.001	1.10 (1.04, 1.15)	<0.001	1.10 (1.04, 1.17)	0.001	1.11 (1.04, 1.17)	<0.001
Built amenity variety			0.92 (0.82, 1.03)	0.146	0.91 (0.82, 1.03)	0.131	0.92 (0.82, 1.03)	0.128
Natural amenities			1.32 (1.10, 1.57)	0.002	1.22 (0.98, 1.51)	0.070	1.28 (1.05, 1.56)	0.014
Park size			1.00 (1.00, 1.00)	0.610	1.00 (1.00, 1.00)	0.667	1.00 (1.00, 1.00)	0.683
Mean slope in park			1.03 (1.00, 1.05)	0.039	1.02 (0.99, 1.05)	0.124	1.02 (0.99, 1.05)	0.158
Net residential density					1.00 (1.00, 1.01)	0.517	1.00 (1.00, 1.01)	0.457
Employment FAR					0.95 (0.77, 1.17)	0.604	0.93 (0.76, 1.14)	0.477
Restaurant density					0.82 (0.37, 1.82)	0.622	0.82 (0.37, 1.83)	0.635
Discrete park density					13.5 (0.0, 2.8E+7)	0.725	0.3 (0.0, 8.6E+4)	0.849
Park area density					1.02 (0.79, 1.32)	0.892	1.11 (0.88, 1.40)	0.378
Intersection density					0.41 (0.07, 2.45)	0.331	0.38 (0.07, 2.15)	0.277
Sidewalk density					1.01 (1.00, 1.02)	0.107	1.01 (1.00, 1.02)	0.111
Mean slope in neighborhood					1.03 (0.98, 1.10)	0.246	1.04 (0.98, 1.10)	0.162
Wealth					1.00 (1.00, 1.01)	0.231	1.01 (1.00, 1.01)	0.201
Duration							1.00 (1.00, 1.01)	0.004
Quarter, 1st							Reference	
2nd							0.97 (0.70, 1.35)	0.853
3rd							0.92 (0.57, 1.49)	0.740
4th							0.78 (0.49, 1.24)	0.302
Weekend							1.06 (0.94, 1.20)	0.343
Start time, <11am							Reference	
11am-3pm							0.94 (0.80, 1.10)	0.411
>3pm							0.95 (0.80, 1.11)	0.497
Temperature							1.00 (0.99, 1.02)	0.700
Precipitation							1.04 (0.91, 1.18)	0.585
Travel diary reported							1.12 (0.96, 1.32)	0.151

	Model 1		Model 2		Model 3		Model 4	
Variable	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**	**RR (95% CI)**	**p value**
GPS sensed							1.62 (1.27, 2.05)	<0.001
Distance from park to home							0.94 (0.92, 0.96)	<0.001

Appendix F: Frequency of park facilities and amenities present during active visits

Table 2-8: Most frequently occurring facilities in actively visited parks. Frequency of park PA facilities, built amenities, and natural amenities present in park during an active park visit. Percentages represent proportion of total active park visits (n=1,553) during which facility/amenity was present.

Rank	PA facility	n	%	Built amenity	n	%	Natural amenity	n	%
1	Trail	1095	71%	Boat launch	372	24%	Shoreline access	510	33%
2	Walking path	1088	70%	Concessions	363	23%	Natural area	35	2%
3	Play equipment	1002	65%	Fishing area	334	22%	Open space	25	2%
4	Tennis court	817	53%	Dog off leash area	307	20%	Landscaping	20	1%
5	Athletic field	529	34%	Picnic shelter	298	19%	Conservancy	9	1%
6	Trail, regional	428	28%	Community center/ activity building	211	14%	Wetland	9	1%
7	Basketball court	423	27%	Bench	120	8%	Greenbelt	7	<1%
8	Swimming area	386	25%	Drinking fountain	108	7%	Wildlife viewing	5	<1%
9	Open/recreation/grass field	346	22%	Restroom	95	6%	Garden, botanical	3	<1%
10	Wading pool	323	21%	Picnic table/area	88	6%			
11	Multi-use court	291	19%	Parking lot	79	5%			
12	Weight/exercise equipment	213	14%	Stretch area	66	4%			
13	Pool	167	11%	Barbeque	64	4%			
14	Running track	100	6%	Amphitheater	55	4%			
15	Golf course	98	6%	Reservations	47	3%			
16	Bowling green	94	6%	Pier	45	3%			
17	Trail, bike	73	5%	Info kiosk/ interpretive exhibit	40	3%			
18	Soccer field	63	4%	Power (electricity)	36	2%			
19	Baseball field	58	4%	Historic marker/site	35	2%			
20	Garden, community	31	2%	Public art	19	1%			
21	Volleyball court	29	2%	Stairs	19	1%			
22	Cricket field	26	2%	Indoor rental facility	18	1%			
23	Fitness parcourse	23	1%	Recreation building	18	1%			
24	Climbing wall	13	1%	Viewpoint	17	1%			
25	Velodrome	13	1%	Lights	16	1%			
26	Ball field	10	1%	Arts/crafts facility	13	1%			
27	Multi-use field	5	<1%	Model airplane flying area	13	1%			

Rank	PA facility	n	%	Built amenity	n	%	Natural amenity	n	%
28	Horseshoe pit	3	<1%	ADA accessible	8	1%			
29	Bocce ball court	2	<1%	Meeting room	7	<1%			
30	Hockey court	1	<1%	Picnic group area	5	<1%			
31	Skate park	1	<1%	Gazebo/pergola/pavilion	4	<1%			
32	Softball field	1	<1%	Plaza	3	<1%			
33	Tether ball	1	<1%						

Aim 2B: Are park facilities associated with the duration of PA during park visits?

Abstract

Adding facilities that support PA to existing parks could be a cost-effective approach to increase the duration of physical activity (PA) that occurs during park visits. Using objectively measured PA and comprehensively measured park visit data among an urban community-dwelling sample of adults, we tested the association between the variety of park PA facilities and duration of PA during park visits. Cross-classified multilevel models were used to account for the cross-classification of park visits (n=1553) within individuals (n=372) and parks (n=233). Controlling for confounding park and neighborhood characteristics, each additional different PA facility at a park was associated with a 7.3% longer duration of PA bouts that included light activity, and an 8.8% longer duration of MVPA time. This study provides novel evidence that adding PA facilities could increase the amount of PA that visitors obtain while at a park.

Introduction

Physical activity (PA) is associated with reduced risk of cardiovascular disease, obesity, diabetes, osteoporosis, and some cancers (US Department of Health and Human Services 2008). Yet more than 90% of adults in the U.S. do not meet the recommended 30 minutes of at least moderate-intensity PA on most days of the week (Troiano, Berrigan et al. 2008). Public parks are places designed to support PA (Sallis, Floyd et al. 2012) and investing in parks has the potential to increase population levels of PA, especially among those who cannot afford the cost of fee-based recreation or exercise opportunities (e.g., health club membership) (US National Physical Activity Plan Coordinating Committee 2010). Extensive research has focused on the relationship between physical access to parks (i.e., proximity of parks to residence) and PA, with the implicit policy question of how building more parks will increase PA (Bancroft, Joshi et al. 2015). Yet it is the facilities within parks – basketball courts, playgrounds, fields, etc. – that primarily provide environments for PA (Bedimo-Rung, Mowen et al. 2005). Perhaps a more cost-effective approach to increase park-based PA would be to add facilities to existing parks rather than build new parks (Cohen, Marsh et al. 2012).

There is limited evidence that park facilities designed for PA increase the likelihood that a park will be used for PA. The presence of certain facilities and amenities in nearby parks was associated with neighborhood park-based PA (Giles-Corti, Broomhall et al. 2005, Kaczynski and Havitz 2009, Sugiyama, Francis et al. 2010, Kaczynski, Besenyi et al. 2014). But these studies are of limited insight since the facilities measured in neighborhood parks may not necessarily match the specific parks that were used for PA. Two studies using individual-level data examined the relationship between specific parks and the PA that occurred within them. In a study of 1,305 residents of Odense, Denmark (Schipperijn, Bentsen et al. 2013), each additional different feature in the nearest public park was associated with a 3% increase in the odds of reported use for PA at least once a week. The relationship disappeared, however, after controlling for park size and distance to home. In an Ontario, Canada study, Kaczynski et al. (Kaczynski, Potwarka et al. 2008) examined individual-level data at the park level by testing the association between the number of park PA features and whether a park was used for PA by any of 380 adult neighborhood residents as recorded in weeklong activity diaries. The odds of *any* participant using a park for PA doubled for each additional PA facility, an association which held after controlling for park size, mean distance to all participants' homes, and perceived neighborhood safety and aesthetics.

Studies comparing direct observations of active park visitors to sedentary park visitors found that active park visitors were more likely to be in park areas with PA facilities, such as courts, paths, and playgrounds (Shores and West 2008, Floyd, Bocarro et al. 2011). Additionally, installing or upgrading park PA facilities often (Tester and Baker 2009, Cohen, Marsh et al. 2012, Veitch, Ball et al. 2012), but not always (Cohen, Golinelli et al. 2009), led to increases in observed levels of park use and park-based PA.

These prior studies suggest that adding features to parks could result in increased occurrence of any PA during a park visit. A greater variety of park PA facilities appears to increase the likelihood that an individual visitor finds a suitable activity at a park, resulting in any PA during the visit. But a greater variety of park PA facilities could also increase the number of suitable activities that an individual visitor finds at a park, resulting in longer durations of PA. To our knowledge, however, no study has directly investigated the association between park facilities and the duration of PA during park visits. At the population level, park visits are relatively infrequent, occurring at a rate of 1.4 per person-week (Stewart, Moudon et al. 2016). Extending the duration of PA that occurs during visits could be an important approach to increase levels of PA among those who do not visit parks regularly. The present study is designed to fill this gap in the research. We use detailed data on park visitation among adult residents of a large metropolitan area to test for an association between the variety of park facilities that support PA in the park visited and the duration of PA that occurred during the visit. Park visits were measured using both objective (GPS) and subjective (travel diary) instruments, while concurrent park-related PA was measured objectively using accelerometers. These instruments overcome the limitations of reliance on only self-report PA (Sallis and Saelens 2000) and park use (Stewart, Moudon et al. 2016) present in prior research and provide sufficiently precise data to develop a robust estimate of the association between park facilities and the duration of PA during a visit. The results will provide policy-makers, active living researchers, and park managers with a better understanding of how investments in existing parks can affect the health of visitors.

Methods

Study design and sample

This study presents a repeated cross-sectional analysis of data from the Travel Assessment and Community (TRAC) project. The TRAC project was a longitudinal study of travel and activity in relation to light rail implementation in King County, Washington. The sample frame included King County residences in areas proximal (<1 mile) or distal (>1 mile) from planned light rail stations, but with otherwise similar built environments (Moudon, Saelens et al. 2009). Eligible randomly selected households were contacted by telephone and a randomly selected adult was recruited if they were aged 18 or older, able to complete a travel diary and survey in English, and able to walk unassisted for ≥10 minutes. The Seattle Children's Hospital IRB approved the study. A total of 699 enrolled participants completed baseline data collection, 584 and 532 of whom also completed first and second follow-up data collection, respectively. Baseline data collection occurred from July 2008 to July 2009, follow-up data collection occurred 2 and 4 years later. At each time participants completed a survey and provided data on their activities for a one-week period. Follow-up data collection occurred at the same time of year for each participant. Data from all waves were used for analysis to most closely capture usual park-related behavior.

Data collection and measures

Activity

A detailed description of the activity data collection and processing is available elsewhere (Kang, Moudon et al. 2013). Briefly, participants were instructed to wear an accelerometer (GT1M; ActiGraph LLC, Fort Walton Beach, FL, at baseline and GT3X, ActiGraph LLC, Fort Walton Beach, FL, at first and second follow-up), carry a GPS device (DG-100, GlobalSat, Taipei, Taiwan, at baseline and first follow-up and BT-1000XT GPS data logger, Qstarz, Taipei, Taiwan, at second follow-up), and complete a place-based paper travel diary for a one week period. Data from the three instruments for each participant were integrated by time matching GPS and travel diary locations to each 30-second accelerometer epoch (Hurvitz, Moudon et al. 2014). Observation days were considered valid if they had ≥1 place recorded in the travel diary, ≥3 minutes of GPS data, and an accelerometer wear time of ≥8 hours. Accelerometer periods of ≥20 minutes with continuous zeroes were considered non-wear times (Masse, Fuemmeler et al. 2005).

Parks and park facility exposure measures

Park location data were collected from King County and the 39 municipalities located within it in the form of GIS datasets, maps, spreadsheets, city planning documents, and text descriptions in spring 2008 (Stewart, Moudon et al. 2016). We defined parks as publicly owned, freely-accessible, outdoor spaces intended for leisure or recreation and distinct from street right-of-ways. Based on this definition, we excluded aquariums, boulevards, golf courses, pools, community centers, boat launches, wilderness areas, cemeteries and similar places unless they were located entirely within a park that did fit our definition. Data not already stored in a GIS format were digitized using editing tools in ArcGIS 9.2 with the aid of tax parcel data and aerial imagery. Park GIS data from each jurisdiction were then combined to create a single dataset that was the aggregate of all input geometries. The combined dataset contained 1,438 discrete parks.

Park facility and amenity data were then added to each park record using park management databases, inventories, or brochures obtained from each jurisdiction. Facility data were available for 1,080 (75%) parks. Facility data for an additional 23 parks visited by participants but with facility data not available from the initial round of public agency data collection were developed using supplemental material from public agencies or online resources such as Google maps (Taylor, Fernando et al. 2011). Data were recorded as the presence of 103 different facilities/amenities. Facilities/amenities were classified as PA facilities (e.g., tennis courts, fields), built amenities (e.g., barbeques, bathrooms, parking lots), and natural amenities (e.g., shorelines, greenbelts (Appendix A, Table 3-4). This classification is similar to those used by in-person park audit instruments such as the Community Park Audit Tool (CPAT) (Kaczynski, Stanis et al. 2012), the Environmental Assessment for Public Recreation Spaces (EAPRS) instrument (Saelens, Frank et al. 2006), and the Public Open Space Tool (POST) (Giles-Corti, Broomhall et al. 2005). For analysis, park-level facilities/amenities were measured as the count of different PA facilities, the count of different built amenities, and the binary presence of any natural amenities.

Parks were also characterized using GIS measures of size (acres) and mean slope. Sloping terrain within parks may contribute to views, terrain for PA (e.g., stair climbing), and/or space limitations for building facilities/amenities. Slope data came from the U.S. Geological Survey National Elevation Dataset (USGS NED). Elevation data were represented in raster datasets with a cell size of 1/3 arc-second (approximately 10 m), from which mean slope in the park was calculated.

Park visits

Park visits were defined as at least 3 consecutive minutes spent within a park (Evenson, Wen et al. 2013) and were measured using two sources: travel diaries and GPS/GIS data. For each place visited, participants were instructed to record in the travel diary the place name and time of arrival and departure. Travel diary places were reviewed for names matching those of public parks. Matching names were considered park visits if the duration between the arrival and departure time was ≥3 minutes. Each travel diary park visit was linked to a park in the GIS database based on the park name. Park visits were also sensed from the GPS/GIS data using a method similar to that pioneered by Evenson et al. (2013). Sensed visits consisted of ≥3 minutes of consecutive GPS points in the same GIS park polygon, with a speed <30km/h and a distance of >50 meters from the participant's home and work, while allowing for gaps of ≤45 minutes. If a sensed visit temporally overlapped with a visit recorded in the travel diary, the presumably more precise park visitation duration from the GPS data was used.

Park visit PA outcome measures

The primary outcome in this analysis was park visit PA time, defined as the total time spent in PA bouts within the duration of a park visit (Figure 3-1). Lower accelerometer activity count thresholds were used to capture light PA obtained during walking, the most commonly reported form of park-based PA (Godbey and Mowen 2010). Thus PA bouts were defined as time intervals with vertical axis accelerometer counts >500 per 30-second epoch for at least 5 minutes, allowing for counts to drop below that threshold for up to 2 minutes during any 7-minute interval (Kang, Moudon et al. 2013). If PA bout durations extended before/after the beginning/end of a park visit, only the portion of the PA bout that occurred within the duration of the park visit was counted.

Moderate to vigorous physical activity (MVPA) time was explored as a secondary outcome. We hypothesized that a stronger association would exist between park PA facilities and MVPA time since most park facilities are designed for activities more intense than walking. MVPA time was defined as 30-second epochs with accelerometer counts ≥976 per 30-second epoch and temporally within the duration of a park visit, regardless of whether they occurred during bouts (Gorman, Hanson et al. 2014). Both PA outcomes were measured in minutes and log-transformed for analysis.

Other park visit covariates

Park-related PA time that occurred outside the duration of the park visit was measured as a potential covariate. It was intended to capture active travel, such as walking or jogging, to or from the park. We hypothesized that park visits that occurred incidental to walks or jogs would have fewer facilities and shorter PA time within the park visit duration. Park-related PA time before/after the park visit was measured as PA bout time that occurred before or after the park visit, and was part of a bout with at least some time within the park visit duration (Figure 3-1) (Stewart, Moudon et al. 2016). If a single PA bout temporally overlapped with two or more park visits, as would be the case if a participant walked through one park and continued walking to another park, the intermediate park-related PA bout time was assigned to the park visit it preceded.

Characteristics of the park visit included the duration of the visit, quarter of year, day of week (weekend or weekday), time the visit started (before 11am, 11am-3pm, and after 3pm), mean daily temperature (°f), the presence of any precipitation during the day, whether the visit was reported in the travel diary, whether the visit was sensed from GPS data, and the network distance from the participant’s home to the closest point along the park boundary (closest points were identified using Euclidean distances from home to the park boundary). Climatic measures were taken from those reported at Seattle-Tacoma International

Airport by the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration).

Park neighborhood built environment covariates

Built environment (BE) features that support physical activity were measured in the neighborhood immediately surrounding each park as covariates. Park neighborhoods were delineated as 400-meter Euclidean buffers from park perimeters, restricted to the contiguous land area (Figure 3-2). This buffer size was chosen to capture the 2-3 street-block area immediately surrounding each park, which could conceivably draw activity out of the park or to the park and hence confound the effect of park facilities on PA in parks. BE measurements and data sources are detailed in Appendix B. Briefly, BE covariates fell under four domains commonly associated with active living and for which secondary GIS data were available: development density, destinations, transportation systems, and economic environment (Stewart, Carlos et al. 2016). Density variables included net residential density and employment floor-area ratio (FAR), which is a proxy for a pedestrian-oriented site design (Saelens, Sallis et al. 2012). Destination variables included count of restaurants as an indicator of utilitarian destinations and count and acreage of other parks as an indicator of nearby recreational opportunities. Transportation system variables included the count of ≥3-way intersections, the length of sidewalks, and the mean slope of terrain in buffer area. Due to large variations in park neighborhood buffer sizes, destination and transportation variables were standardized by buffer acreage, resulting in density measures (e.g., restaurants per park neighborhood buffer acre). Economic environment was measured as the average King County percentile of the assessed value of residential units (land + improvement).

Sociodemographic covariates

Participants' age, gender, race and ethnicity, and highest level of education were collected only on the baseline survey; values were carried through to the first and second follow-ups. Annual household income and presence of children under age 18 in the household were collected at each observation period. Body Mass Index (BMI) was calculated from reported weight at each observation period and height at baseline. BMI was categorized as underweight or normal (<25), overweight (25-29.9), and obese ($\geq$30 kg/m^2). Single family vs. other residence types (apartment, condo, townhouse, other) was collected at all waves and was included as a proxy for presence of outdoor green space at home as an alternative to the outdoor green space that parks provide.

Analysis

Analysis was conducted at the park visit level. During the three observation periods, 2,451 park visits occurred on valid observation days among 461 unique individuals and 317 unique parks. Due to the high proportion of park visits with no PA (37%) and model limitations for handling both zero-inflated distributions and cross-classified data, we focused on the 1,553 park visits with any PA bout time. Analysis of the relation between different park facilities and the occurrence of any PA is presented elsewhere (aim 2a). The 1,553 park visits with any PA bout time were clustered within 372 individuals and within 233 parks. We first present mean park visit PA bout time by strata of each covariate (continuous covariates were dichotomized at the median to create two strata).

We then used Cross-classified multilevel models (CCMMs) (Beretvas, Meyers et al. 2005) to estimate the association between the count of different PA facilities at parks and the log-transformed duration of PA time. Model coefficients can be interpreted as the estimated multiplicative change in park-related PA per additional type of PA facility at a park. CCMMs account for the clustering of park visits within combinations of individuals and parks through a random effects component at the individual, park, and individual-park combination level (Leckie 2013). The CCMMs were found to fit the data significantly better than both standard single-level regression models and standard hierarchical regression models with no cross-classification (Appendix C, Table 3-5).

We developed CCMMs for each PA outcome by first fitting a null model with no predictors to estimate the variance partition coefficients (VPCs). VPCs are the proportion of the response variance that lies at each level of the model hierarchy (Leckie 2013). In this case the VPCs can be interpreted as the relative magnitude of the variance in PA attributable to the park visit, the individual visitor, the unique park, and individual-park combination. Next, we fit a model with only the count of different park PA facilities to estimate the crude association between the variety of park PA facilities and PA, as well as to identify how the variance in park-related PA is explained by the variety of park PA facilities. We then selected model covariates among those hypothesized to confound the association using the change-in-estimate (CIE) criterion with a 10% cutoff (Weng, Hsueh et al. 2009, Lee 2014) and fit a final model that included all covariates that individually changed the exposure-outcome estimate by 10% or more.

Results

Park visits with any concurrent PA bout time lasted an average of 41.4 (SD=55.6) minutes, with an average PA bout time of 19.3 (SD=23.1) minutes. In this sample data, average PA bout times were longest in the winter and shortest in the summer but similar for visits above and below the median daily average temperature (55°f) and on days with and without precipitation (Table 3-1). PA bout times tended to be longer during weekend visits and visits before 3pm. Average PA bout time was longer for visits recorded in the travel diary and not sensed with GPS data. Average PA bout time was longer for visits to parks further from home and with less park-related PA bout time before or after the visit. Mean PA bout time during park visits did not vary substantially by individual-level sociodemographic characteristics of park visitors. Larger parks with more facilities and amenities tended to have longer durations of PA bout time. PA time was also lower in parks in less urbanized neighborhoods, as measured by residential density, employment FAR, restaurant density, density of other parks, intersection density, and sidewalk density. PA time tended to be longer in parks in wealthier neighborhoods.

Based on crude CCMM model results, PA bout time during park visits where any PA occurred was an average of 10.0% greater for each additional different PA facility in the park (95% CI: 5.6%, 14.5%; $p<0.001$) (Table 3-2). Confounding covariates, defined as variables that individually changed the PA facility-PA duration association by at least 10%, were identified in the park and park neighborhood domains. Park characteristics included slope and variety of built amenities. Park neighborhood characteristics included net residential density, employment FAR, restaurant density, park count density, and slope. After adjusting for these confounders, each additional different PA facility was associated with a 7.3% longer PA bout duration (95% CI: 3.0%, 11.6%; $p=0.001$).

Among the 1502 park visits with any MVPA time, the mean duration of park visit MVPA time was 15.6 (SD=19.3) minutes. Each additional different PA facility was associated with an unadjusted 10.9% greater duration (95% CI: 6.6%, 15.3%; $p<0.001$) (Table 3-3). Confounding covariates were the same as for the PA bout time outcome. After adjusting for these confounders, each additional different PA facility was associated with 8.8% more MVPA time (95% CI: 4.7%, 13.0%; $p<0.001$).

The variance partition coefficients (VPCs) for the models of PA bout and MVPA time during the park visit were similar (Table 3-2 and Table 3-3). Null models indicated that most of the variance in these outcomes was at the park level (41% and 37% for PA bout and MVPA time, respectively), and very little variance was at the individual level (5% and 3% for PA bout and MVPA time, respectively). Adding the variety of PA facilities to the model reduced the variance at the park level and the total variance; fully adjusted models further reduced the total variance, primarily through reduced variance at the park level.

Discussion

Detailed and objective measures of park facilities, park visitation, and PA that occurred during visitation allowed us to investigate the association between park facilities and the duration of PA that occurs during park visits. Each additional different PA facility was associated with a 7.3 and 8.8% greater duration of PA bout and MVPA time, respectively, during the park visit. These results complement the small body of research using individual-level data to demonstrate an association between park facilities and the occurrence of any park-based PA (Kaczynski, Potwarka et al. 2008, Schipperijn, Bentsen et al. 2013). Providing a greater variety of PA facilities at each park appears to be a cost-effective way to increase both the occurrence and duration of park-based PA.

Adding an additional type of PA facility at a park was estimated to increase the amount of PA and MVPA time by 1.4 and 1.3 minutes, respectively, for the average visit. While this is a small increase, it has the potential to add up to substantial population health improvements when applied to all active visits that occur at a park. Adding multiple different types of PA facilities to a single park would deliver even greater increases, as exploratory analysis found the relationship between park PA facilities and PA time to be roughly linear across the entire range of different park PA facilities (0-13), but with substantial increases occurring with 4 or more facilities (Appendix D, Table 3-6). Park designers should not be shy to install a wide variety of PA facilities in parks, so long as the facilities do not interfere with other park functions, such as ecological processes, providing view sheds, or places for contemplation.

We observed only a slightly stronger association for MVPA time compared to PA bout time that included both MVPA and lighter PA, such as walking. This suggests that park PA facilities do not only contribute to intense activities (e.g., running or soccer) that may be considered too intimidating for participation among sedentary or elderly people.

Measures of park neighborhood development (net residential density, employment FAR) and activity destinations (restaurants, other parks) confounded the association between park facilities and PA duration outcomes. Greater PA durations tended to occur during visits to parks in less developed areas (Table 3-1), where the parks themselves may also be less developed and contain fewer PA facilities. Visits to parks in less developed areas are likely for pre-planned activities where the visitor seeks a specific park characteristics or facility. Park managers could solicit community input to ensure that desired park characteristics are located in parks closer to homes, which may lead to park-based activities with longer PA durations also being more convenient to access and therefore occurring more frequently.

Prior research using direct observation observed an association between park neighborhood socioeconomic status (SES) and park PA levels (Van Dyck, Sallis et al. 2013, Baran, Smith et al. 2014). In our study neighborhood wealth did not confound the association between park facility variety and duration of PA during park visits. Park neighborhood SES is likely more impactful on whether an individual visits a park at all rather than how long an individual is active during a visit. Additionally "equitable differences" were found in Seattle parks, whereby facility quality (measured as the condition and cleanliness of the facility) was negatively associated with neighborhood wealth (Engelberg, Conway et al. 2016). In this analysis, the possible confounding role of neighborhood wealth could have been counterbalanced by higher quality facilities in lower income neighborhoods. Unfortunately due to the extent of the parks involved in this study, park quality as well as social environment conditions of the park, such as safety, could not be explored.

The results of this study do not provide explicit guidance on which specific PA facilities should be added to parks to make the greatest impact on park-based PA. CCMM results showed that much of the variance in PA duration occurred at the individual-park visit combination level. This implies that the amount of time an individual is active during a park visit depends largely on individual preferences for activities and whether or not facilities that support those activities are present at a park. Community input is likely the best way to identify which PA facilities will get the most use among those who visit or could visit or live near a specific park. Regular feedback may be necessary to ensure park PA facilities keep pace with changing community demographics and/or secular trends in recreation.

Limitations

We employed CCMMs to examine park visit data cross-classified within parks and individuals to provide a valid estimate of the association between PA facilities at parks and the duration of PA that occurs during active visits to them. This approach's drawback is that inference is limited to individuals who are active during park visits. Further research is necessary to identify how to increase park-based PA among individuals who are not already active during park visits or do not visit parks at all. Natural experiments examining changes to individuals' park-based PA behaviors in response to changes in park PA facilities could overcome this limitation and provide insight into how changes to PA facilities might affect those who do not often use parks for PA. This would also provide greater evidence of causation than provided by the present study using cross-sectional data. A more spatially distributed sample would also be necessary to understand if the results were generalizable beyond the highly urbanized sample used in the present study.

The results may also be biased due to differential reporting of PA facilities across jurisdictions where parks were visited. However, the vast majority (81%, 1262 of 1553 park visits) occurred in parks with facility data provided by a single jurisdiction (Seattle). When analyses were restricted to these parks, stronger adjusted associations were observed for both PA bout duration (coefficient = 12.1%; 95% CI = 5.8%, 18.5%; $p<0.001$) and MVPA duration (coefficient = 13.6%; 95% CI = 7.7%, 19.5%; $p<0.001$). Non-differential misclassification of facilities across jurisdictions likely resulted in an observed association weaker than the true association. Finally, misclassification of PA facilities may have occurred if PA facilities were installed or closed after park data were collected at baseline. This was probably minimal, as park facilities are relatively fixed. The study period corresponded with a recession during which capital investments in parks were likely minimal and maintenance and operation of existing facilities could have declined. Conversely, this period also coincided with the allocation of dedicated funds for parks from the 2008 passage of a parks levy in Seattle. A detailed assessment of park facility conditions and changes across the study period was beyond the scope of the current research. Similar studies in the future would benefit not only from consistent and timely park facility data for all parks visited, but also from detailed data on the conditions of facilities and other social environment factors that may affect park visitation, such as safety and incivilities (Bedimo-Rung, Mowen et al. 2005).

Conclusion

This study was the first to our knowledge to test the association between PA facilities at parks and the duration of PA that occurs during visits. Each additional different PA facility was associated with a 7.3% longer time in PA bouts that included light activity such as walking. A similar association was observed for MVPA during the park visit. Adding PA facilities could increase the amount of PA that visitors obtain while at a park, across a range of intensities. Ongoing community input is necessary to identify which facilities will have the greatest impact on the duration of park-based PA at a specific park.

Tables and Figures

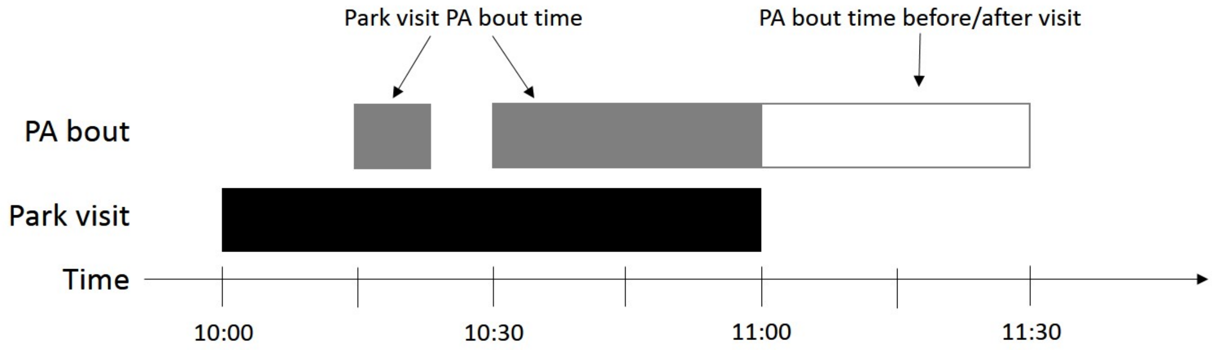


Figure 3-1: Timeline illustrating physical activity (PA) visit bout time as the sum of PA bout time within park visits and PA bout time before/after visit as PA bout time that occurred before or after the park visit, but was part of a bout with at least some time within the park visit duration.

Figure 3-2: Illustration of 400m park neighborhood buffer clipped to land area on which park is located. Park is shown in dark green; land area is shown in grey, water area is shown in blue, and park neighborhood buffer is shown in yellow-green.

Table 3-1: Mean PA bout time during park visits by visit-, individual-, and park-level covariates. For individual- and park-level covariates, distribution of observations by covariate stratum are provided for park visits as well as unique individuals or parks.

			Park visits (n=1553)	
Park visit-level variables	**Category**		**N (%)**	**Mean (SD) PA bout time**
Quarter	1st (January – March)		409 (26)	22.2 (24.8)
	2nd (April – June)		575 (37)	19.4 (24.2)
	3rd (July – September)		435 (28)	16.6 (19.1)
	4th (October – December)		134 (09)	19.1 (24.0)
Weekend	No		999 (64)	17.6 (19.6)
	Yes		554 (36)	22.5 (28.1)
Start time	<11am		496 (32)	20.3 (24.1)
	11am-3pm		495 (32)	21.5 (26.4)
	>3pm		562 (36)	16.6 (18.4)
Temperature (°f)	< Median (55)		778 (50)	19.7 (22.1)
	≥ Median (55)		775 (50)	19.0 (24.0)
Precipitation	No		788 (51)	18.8 (22.6)
	Yes		765 (49)	19.9 (23.7)
Travel diary reported	No		965 (62)	14.1 (17.6)
	Yes		588 (38)	27.9 (28.0)
GPS sensed	No		131 (08)	24.8 (24.8)
	Yes		1422 (92)	18.8 (22.9)
Distance from park to home (network Km)	< Median (1.9)		778 (50)	14.0 (16.2)
	≥ Median (1.9)		775 (50)	24.6 (27.4)
Park-related PA bout time before/after park visit (minutes)	< Median (8.5)		777 (50)	26.4 (26.5)
	≥ Median (8.5)		776 (50)	12.3 (16.3)
		Individuals (n=372)	**Park visits (n=1553)**	
Individual-level variables	**Category**	**N (%)**	**N (%)**	**Mean (SD) PA bout time**
Age	≤45	138 (38)	565 (38)	18.4 (22.6)
	45-64	173 (48)	714 (48)	20.7 (25.2)

	≥65	51 (14)	223 (15)	18.0 (17.7)
Gender	Female	236 (64)	1056 (68)	18.6 (21.5)
	Male	135 (36)	496 (32)	20.9 (26.2)
Race/ethnicity	Other	69 (19)	283 (18)	19.2 (20.2)
	non-Hispanic white	300 (81)	1263 (82)	19.3 (23.7)
Education	no college degree	83 (23)	260 (17)	19.7 (25.5)
	4-year degree	133 (37)	565 (38)	20.2 (24.6)
	graduate degree	146 (40)	676 (45)	18.7 (21.0)
Household income	<$30k	57 (16)	179 (12)	20.5 (29.1)
	$30-$60k	91 (26)	392 (27)	18.7 (19.7)
	$60-$90k	71 (20)	303 (21)	21.1 (24.1)
	>$90k	131 (37)	595 (41)	18.8 (22.6)
Children <18 years old in household	No	249 (71)	1036 (70)	19.1 (23.6)
	Yes	104 (29)	442 (30)	20.1 (21.5)
Body Mass Index (k/m^2)	≤25	197 (57)	918 (63)	19.5 (23.5)
	25-30	97 (28)	357 (25)	19.5 (23.6)
	≥30	51 (15)	172 (12)	20.7 (23.4)
Single family home	No	165 (47)	601 (41)	19.9 (25.9)
	Yes	188 (53)	866 (59)	19.2 (21.5)

		Parks (n=233)	Park visits (n=1553)	
Park-level variables	Category	N (%)	N (%)	Mean (SD) PA bout time
PA facility variety (count)	< Median (4)	129 (55)	466 (30)	14.9 (25.0)
	≥ Median (4)	104 (45)	1087 (70)	21.2 (22.0)
Built amenity variety (count)	< Median (2)	140 (60)	714 (46)	13.5 (18.0)
	≥ Median (2)	93 (40)	839 (54)	24.3 (25.7)
Natural amenities (any)	No	148 (64)	882 (57)	14.6 (17.7)
	Yes	85 (36)	671 (43)	25.6 (27.5)
Park size (acres)	< Median (12.0)	117 (50)	444 (29)	11.6 (16.6)
	≥ Median (12.0)	116 (50)	1109 (71)	22.4 (24.6)
Mean slope in park (percentage)	< Median (3.3)	117 (50)	670 (43)	18.9 (21.7)
	≥ Median (3.3)	116 (50)	883 (57)	19.6 (24.1)

Net residential density (units/residential acre)	< Median (9.7)	122 (52)	709 (46)	21.0 (25.7)
	≥ Median (9.7)	111 (48)	844 (54)	17.9 (20.5)
Employment FAR (employment building acre/ land acre)	< Median (0.28)	119 (51)	730 (47)	23.4 (26.7)
	≥ Median (0.28)	114 (49)	823 (53)	15.7 (18.6)
Restaurant density (count/buffer acre)	< Median (0.22)	117 (50)	704 (45)	21.5 (25.2)
	≥ Median (0.22)	116 (50)	849 (55)	17.5 (21.1)
Park count density (count/buffer acre)	< Median (0.0084)	123 (53)	716 (46)	25.4 (26.6)
	≥ Median (0.0084)	110 (47)	837 (54)	14.2 (18.1)
Park area density (park acre/buffer acre)	< Median (0.12)	124 (53)	669 (43)	18.8 (20.9)
	≥ Median (0.12)	109 (47)	884 (57)	19.7 (24.6)
Intersection density (count/buffer acre)	< Median (0.243)	129 (55)	544 (35)	24.9 (28.1)
	≥ Median (0.243)	104 (45)	1009 (65)	16.3 (19.3)
Sidewalk density (m/buffer acre)	< Median (0.33)	131 (56)	445 (29)	22.9 (28.0)
	≥ Median (0.33)	102 (44)	1108 (71)	17.9 (20.6)
Mean slope in neighborhood (percentage)	< Median (0.482)	123 (53)	700 (45)	19.8 (22.8)
	≥ Median (0.482)	110 (47)	853 (55)	18.9 (23.4)
Wealth (mean percentile of assessed residential unit values)	< Median (47)	127 (55)	511 (33)	15.1 (18.1)
	≥ Median (47)	104 (45)	1039 (67)	21.4 (25.0)

Table 3-2: Cross-classified multilevel model (CCMM) results for the outcome of PA bout time (log transformed) during park visits (n=1553)

	Null		Crude		Adjusted	
Fixed effects parameters	**Coefficient (95% CI)**	**p-value**	**Coefficient (95% CI)**	**p-value**	**Coefficient (95% CI)**	**p-value**
Intercept	2.190 (2.054, 2.326)	<0.001	1.790 (1.570, 2.011)	<0.001	1.843 (1.493, 2.194)	<0.001
PA facility variety			0.100 (0.056, 0.145)	<0.001	0.073 (0.030, 0.116)	0.001
Mean slope in park					0.025 (-0.003, 0.053)	0.081
Built amenity variety					0.034 (-0.004, 0.073)	0.076
Net residential density					-0.004 (-0.009, 0.000)	0.050
Employment FAR					0.054 (-0.159, 0.267)	0.619
Restaurant density					-0.004 (-0.875, 0.866)	0.992
Park count density					-23.381 (-33.150, -13.613)	<0.001
Mean slope in neighborhood					0.043 (-0.005, 0.090)	0.082
Random effects parameters	Variance (95% CI)	VPC	Variance (95% CI)	VPC	Variance (95% CI)	VPC
Individual-park combination	0.346 (0.260, 0.461)	23%	0.346 (0.259, 0.462)	24%	0.364 (0.274, 0.484)	30%
Park	0.617 (0.447, 0.853)	41%	0.511 (0.356, 0.733)	36%	0.309 (0.195, 0.488)	25%
Individual	0.070 (0.028, 0.176)	5%	0.075 (0.031, 0.180)	5%	0.063 (0.023, 0.174)	5%
Park visit	0.489 (0.440, 0.544)	32%	0.490 (0.440, 0.546)	34%	0.490 (0.440, 0.546)	40%
Model fit						
AIC	4266.82		4250.70		4215.62	
BIC	4293.56		4282.78		4285.15	

CI = Confidence Interval, VPC = Variance Partition Coefficient, AIC = Akaike information criterion, BIC = Bayesian information criterion

Table 3-3: Cross-classified multilevel model (CCMM) results for the outcome of MVPA time (log transformed) during park visits (n=1502)

	Null		Crude		Adjusted	
Fixed effects parameters	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
Intercept	1.872 (1.736, 2.008)	<0.001	1.432 (1.214, 1.651)	<0.001	1.514 (1.166, 1.862)	<0.001
PA facility variety			0.109 (0.066, 0.153)	<0.001	0.088 (0.047, 0.130)	<0.001
Mean slope in park					0.012 (-0.015, 0.040)	0.378
Built amenity variety					0.011 (-0.026, 0.047)	0.577
Net residential density					-0.006 (-0.010, -0.002)	0.008
Employment FAR					0.107 (-0.102, 0.315)	0.317
Restaurant density					-0.099 (-0.937, 0.739)	0.817
Park count density					-25.491 (-35.054, -15.928)	<0.001
Mean slope in neighborhood					0.064 (0.016, 0.112)	0.009
Random effects parameters	Variance (95% CI)	VPC	Variance (95% CI)	VPC	Variance (95% CI)	VPC
Individual-park combination	0.437 (0.336, 0.568)	28%	0.437 (0.335, 0.569)	30%	0.457 (0.353, 0.592)	37%
Park	0.572 (0.407, 0.805)	37%	0.438 (0.292, 0.657)	30%	0.238 (0.140, 0.403)	19%
Individual	0.055 (0.015, 0.203)	3%	0.065 (0.021, 0.203)	4%	0.049 (0.012, 0.207)	4%
Park visit	0.501 (0.449, 0.559)	32%	0.502 (0.450, 0.561)	35%	0.502 (0.449, 0.560)	40%
Model fit						
AIC	4214.24		4194.51		4154.43	
BIC	4240.82		4226.39		4223.52	

CI = Confidence Interval, VPC = Variance Partition Coefficient, AIC = Akaike information criterion, BIC = Bayesian information criterion

Appendix A: Park facility and amenity classification

Table 3-4: Park facility and amenity classification

Physical activity (PA) facility	Built amenity	Natural amenity
Athletic field	ADA accessible	Arboretum
Ball field	Amphitheater	Beach/waterfront/shoreline access
Baseball field	Arena	Conservancy
Basketball court	Arts/crafts facility	Garden, botanical
Batting cage	Barbeque	Garden, unspecified
BMX course	Bench	Greenbelt
Bocce ball court	Boat launch	Landscaping
Bowling green	Camping	Natural area
Climbing wall/boulders	Chess table	Open space
Cricket Field	Clubhouse	Undeveloped
Dance studio	Community center/activity building	Wetland
Disc golf course	Concessions	Wildlife viewing area
Equestrian facility	Dog off leash area	
Fitness parcourse	Drinking fountain	
Football field	Farm	
Garden, community	Fish ladder/hatchery	
Golf course	Fishing area	
Gym	Fountain/water feature	
Handball court	Gazebo/pergola/pavilion	
Hang gliding field	Historic marker/site	
Hockey court	Indoor facility	
Horseshoe pit	Indoor rental facility	
Lacrosse field	Info kiosk/interpretive exhibit	
Multi-use court	Lights	
Multi-use field	Meeting room	
Open/recreation/grass field	Model airplane flying area	
Pickle ball/badminton court	Parking lot	
Play equipment	Picnic group area	
Pool	Picnic shelter	
Roller hockey court	Picnic table/area	
Running track	Pier	
Skate park	Plaza	
Soccer field	Pool table	
Softball field	Power/electricity	
Spray park	Public art	
Swimming area	Recreation building	
Swing	Reservations	
Tennis court	Restroom	
Tether ball	School	

Physical activity (PA) facility	Built amenity	Natural amenity
Trail	Senior facility	
Trail, bike	Stairs	
Trail, regional	Stretch area	
Velodrome	Viewpoint	
Volleyball court		
Wading pool		
Walking path		
Weight/exercise equipment		
Zip line		

Appendix B: BE variable measurement details

Nine BE covariates were measured under four domains commonly used in active living research and for which secondary GIS data were available: development density, destinations, transportation systems, and economic environment (Stewart, Carlos et al. 2016).

Density characterizes the intensity of human activity that corresponds to a primary land uses, it is closely related to other built environment constructs such as land use mix and street network design (Ewing 1995, Cervero and Kockelman 1997, Rodriguez, Evenson et al. 2009, Frank, Sallis et al. 2010). Density variables included the number of residential units per acre of residential land and the square footage of buildings used for employment per square footage of land used for employment. The number of residential units per acre of residential land is commonly referred to as net residential density. All residential land uses, including multi-family dwellings such as apartments, condominiums, and mixed-use buildings were included in the count of residential units. Employment land uses include commercial, industrial, governmental, and all other places where people work regularly outside the home. The square footage of buildings used for employment per square foot of land or parcels housing the buildings results in the floor-area ratio (FAR). FAR is accepted as a common measure of pedestrian-oriented site design (Saelens, Sallis et al. 2012). Data were derived from the King County Assessor's parcel database for the years 2008, 2010, and 2013 to correspond with baseline and first and second follow-up.

Destinations are specific travel "attractors" that may also act as environmental stimuli. They fulfill needs for daily living, such as shopping and socializing, while also affecting sights, sounds, smells, and general environmental cognition (Cerin, Leslie et al. 2007, Moudon, Lee et al. 2007, McCormack, Giles-Corti et al. 2008, Rodriguez, Evenson et al. 2009). In this study destinations were captured through the count of restaurants and the count and acres of other parks per acre of buffer. Restaurants were associated with neighborhood walking for utilitarian purposes in a variety of built environments (Stewart, Vernez Moudon et al. 2016) and serve as a proxy for other retail and entertainment destinations. Restaurant data were derived from geocoded Public Health Seattle-King County food service permits for the years 2008 (baseline) and 2013 (first and second follow-up) (Moudon, Drewnowski et al. 2013). Nearby parks and park land may act as competing locations for park-based activities.

Transportation systems describe the physical form of the transportation network and opportunities for accessibility and movement (Cervero and Kockelman 1997, Frank, Schmid et al. 2005, Frank, Sallis et al. 2010). In this study, transportation system characteristics were measured as the count of ≥3-way intersections, the length of sidewalks per acre of the buffer area, and the mean slope in buffer area. Intersection density captures the block size and option for various routes, which may allow for safer or more comfortable travel (Berrigan, Pickle et al. 2010). Intersections were derived from the pedestrian-accessible King County Transportation network, which excluded freeways and other roadways where pedestrians are legally not allowed. Multiple intersections ≤50 feet apart were dissolved into one intersection to account for spatial representations of the street network that would otherwise lead to an over count of intersections (e.g., two line segments often represented one street divided by a median and would result in two intersections when it met a cross-street) (Design For Health 2012). Linear sidewalk density was measured as the length of the King County street network with full sidewalk coverage on both sides of the street per acre of the buffer area (Kang, Scully et al. 2015). Presence of sidewalks along streets were intended to capture the comfort and safety of pedestrian routes to or from the park. Slope data were derived from the U.S. Geological Survey National Elevation Dataset (USGS NED). Elevation data were represented in raster datasets with a cell size of 1/3 arc-second (approximately 10 m), from which slope was calculated. Slope captures the exertion required to access the park on foot as well as the potential for visual interest (Lee and Moudon 2006).

Economic environment variables capture the wealth and value of the built and natural environment and serve as a proxy for the wealth or deprivation of neighborhood residents (Krieger, Williams et al. 1997, Moudon, Cook et al. 2011). Economic environment was measured as the average King County percentile of the assessed value of residential units (land + improvement). Data were derived from the King County Assessor’s parcel database for the years 2008, 2010, and 2013 to correspond with baseline and first and second follow-up. Residential wealth is conceptualized to be a relative measure, and thus percentiles of residential assessed values were used to account for the secular decline in property values during the study period (King County median assessed residential unit values declined from $309,727 in 2008 to $262,996 in 2013).

Appendix C: Model selection criteria

Cross-classified multi-level models (CCMMs) were chosen because they exhibited significantly better fit than standard hierarchical models based likelihood ratio tests, as well as lower Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) scores (Table 3-5).

Table 3-5: Model selection criteria. Comparison of null model fit between standard, hierarchical, and Cross-classified multilevel model (CCMM) fit for PA outcomes.

Outcome		Standard regression	Standard hierarchical	LR test*	CCMM	LR test**
PA bout time (n=1553)	AIC	4849.80	4340.63	<0.001	4266.82	<0.001
	BIC	4855.15	4362.02		4293.56	
MVPA time (n=1502)	AIC	4797.58	4306.32	<0.001	4214.24	<0.001
	BIC	4802.89	4327.58		4240.82	

AIC = Akaike information criterion, BIC = Bayesian information criterion

* Likelihood-ratio test comparing standard regression with standard hierarchical regression model

** Likelihood-ratio test comparing standard hierarchical regression with CCMM regression model

Appendix D: Exploration of non-linear trends

Table 3-6 presents the association between PA facility variety quintiles and PA and MVPA duration outcomes. Linear trends in associations were observed across quintiles of park PA facilities for both PA outcomes. Associations, however, did not approach significance until the 4th quintile of PA facility variety.

Table 3-6: Exploration of non-linear trends for park facilities and PA duration. Cross-classified multilevel model (CCMM) results using a categorical variable for park facilities to explore the possibility of non-linear trends. Models adjusted for slope and variety of built amenities within the park, as well as park neighborhood net residential density, employment FAR, restaurant density, park count density, and slope.

	PA bout time (n=1553)		MVPA time (n=1502)	
PA facility variety	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
1st quintile (0-3)	0.000	Ref.	0.000	Ref.
2nd quintile (4)	-0.061 (-0.423, 0.302)	0.743	0.011 (-0.347, 0.369)	0.951
3rd quintile (5-6)	0.225 (-0.089, 0.539)	0.160	0.203 (-0.103, 0.508)	0.194
4th quintile (7-8)	0.333 (-0.013, 0.679)	0.059	0.507 (0.175, 0.838)	0.003
5th quintile (9-13)	0.537 (0.061, 1.013)	0.027	0.668 (0.213, 1.123)	0.004

Conclusion

In this dissertation we used a life segment epidemiology approach (Chaix, Kestens et al. 2016) to assess how park proximity and park facilities are associated with PA. We identified park visits and corresponding park-based PA from timestamp-linked travel diary, GPS, and accelerometer data obtained over up to 3 weeklong observation periods from a sample of urban-living adults. Park visit data enabled us to isolate and analyze the mechanism through which parks contributed to PA.

We found that a greater count and area of home neighborhood parks were associated with park-based PA that corresponded with visits to home neighborhood parks. Among those with at least one park in their home neighborhood, however, an average of only 1.2 minutes (3%) of the 42.7 total minutes of daily PA occurred in home neighborhood parks. Because count or area of home neighborhood parks were not associated with other non-park PA, which accounted for an average of 38.0 minutes (89%) of total daily PA, we did not observe an association between home neighborhood park proximity and total PA. This likely explains the null results found in the bulk of prior research assessing park proximity and objectively measured total PA among adults (Bancroft, Joshi et al. 2015).

This dissertation also confirms prior research that observed a positive association between the variety of PA facilities at a park and park PA levels based on activity diary (Kaczynski, Potwarka et al. 2008) and direct observation (Cohen, Marsh et al. 2012). This dissertation is the first, however, to provide an estimate of the effect of PA facilities on an individual when he or she visits a park and therefore offers greater insight into how a greater variety of facilities contributes to increased PA. We estimate that each additional different park PA facility is associated with a 7% greater probability that an individual is active during a park visit, and a 7% greater duration of park PA when an individual is active.

Our approach of observing the mechanism through which parks contribute to PA provides strong evidence for a direct association between physical park characteristics and park-related PA, yet it falls short of providing an estimate of the causal effect of parks on park-related PA. Individuals may decide a priori to be active, then choose to be active at a park due to proximity or facilities. For example, an individual may choose to play basketball, then seek a park with many PA facilities including a basketball court, then obtain PA by playing basketball. In this example, the park with the basketball court is necessary for playing basketball (and hence PA), but did not cause the PA.

Future research should take advantage of natural experiments to understand how the addition or removal of parks and/or park facilities change park-based and total PA among nearby residents. Prospective cohort studies using GPS, travel diary, and accelerometer instruments to observe changes in behavior as parks open or close, or as participants relocate to neighborhoods with more or fewer parks would provide more robust evidence on how much nearby parks cause the decision to be active versus merely provide a convenient setting for a pre-determined activity. This research approach would be particularly useful in testing whether changing home neighborhood park exposure would have any effect on those who never or very infrequently visit parks, which comprised roughly a third of this study sample (n=238) and who were also of lower socio-economic status and more likely to be overweight or obese.

Future research using GPS, travel diary, and accelerometer instruments could also help refine measures of park visitation. We used an established 3-minute duration as our minimum threshold to identify park visits (Evenson, Wen et al. 2013). This minimum duration is likely much shorter than many visits for the express purpose of recreating at a park – it undoubtedly captures a substantial number of visits incidental to the park, such as walks or bike rides through parks to other destinations. Intentional and incidental park visits may contribute to PA differentially as well as exhibit different associations with individual and park characteristics. Planning and managing park systems for intentional versus incidental users may require a separate set of strategies. Since it is not possible to discern intention directly from GPS activity data, structured interviews could be used to retrospectively review participants' park-based GPS traces, ascertain intent, and develop an understanding of how intentional and incidental park visits differ.

Given the appropriate data, the life segment approach could also be taken further by analyzing park-based PA at finer spatial and temporal scales. For example, overlaying time-matched GPS and accelerometer data with specific geo-located facilities within parks could help identify which park facilities contribute the most to park-based PA. Identifying GPS traces of active travel routes to/from parks and corresponding street features along the routes could result in a more robust understanding of the park neighborhood built environment that facilitates park-related PA. Individual measures of daily mobility patterns may also provide insight into how parks are used. For example, participants whose spatial realms contain many parks may be more likely to visit parks, even if they have few near home. Such nuanced park exposure measures could contribute to an even more precise understanding of how proximity to parks is associated with visitation and PA. Finally, if GPS traces from large, representative samples of the population – perhaps from cellular phone carriers – become available to researchers, then park use could be understood much more completely within specific parks. These data could be used to identify inaccessible park areas, park access points, and more or less popular park areas. Practitioners could understand park use more completely without the burden of direct observation. Refinements could be made to park GIS data to help researchers eliminate inaccessible parks from analyses and take more precise proximity measure to access points instead of working under the assumption that parks are completely permeable and accessible, as was done in this dissertation.

Despite our lack of ability to definitively infer a causal association, work at the somewhat spatially and temporally coarse park visit level, and some assumptions about park accessibility, our combined results provide solid support for the strategy of increasing residential proximity to parks and adding PA facilities to parks as a means to reduce physical inactivity. Expanding or improving the physical environment of parks may result in larger gains in PA when paired with public outreach and/or programing to encourage the decision to be active in a park (Cohen, Han et al. 2013). Outreach may also help inform efforts to make parks more accessible to surrounding residents. Parks may be proximal, but inaccessible due to unsafe conditions or inappropriate facilities. Nevertheless, even these more comprehensive strategies to increase park-based PA will likely have a limited impact on total PA, since park-based PA accounted for only about 10% of total PA and park visits occurred at a rate of 1.4 per person-week. Increasing park-based PA should be viewed as just one component of a diversified approach to build a physical, social, and institutional environment that makes physical activity an easy choice.

Park system planners may achieve a greater impact on PA by providing proximal parks for sub-populations who are more likely to benefit from them. Home neighborhood parks were more strongly associated with home neighborhood park PA among adults with children or dogs in their household. Park system planners should also recognize that the spatial layout of parks in the home neighborhood might influence where park-based PA occurs. Non-home neighborhood park PA was positively associated with the count, but negatively associated with the area, of home neighborhood parks. This apparent contradictory finding could suggest that a series of many small, adjacent parks may act as a "parkway," facilitating active travel beyond the home neighborhood. Conversely, larger parks may concentrate park-based PA in the home neighborhood, with possible implications for neighborhood social cohesion. A series of large parks linked by smaller parkways may provide an ideal balance whereby large parks with many facilities are made accessible via park-like settings for the greatest proportion of the population. Creating parkways through linked smaller parks may be more feasible in highly developed urban areas where open space for large parks is not readily available. Finally, installing additional different PA facilities may be a cost-effective approach to support park-based PA in any park.

References

Abercrombie, L. C., J. F. Sallis, T. L. Conway, L. D. Frank, B. E. Saelens and J. E. Chapman (2008). "Income and racial disparities in access to public parks and private recreation facilities." Am J Prev Med **34**(1): 9-15.

Agresti, A. (2001). Categorical Data Analysis. New York, Wiley.

Anderson, L. H., B. C. Martinson, A. L. Crain, N. P. Pronk, R. R. Whitebird, P. J. O"Connor and L. J. Fine (2005). "Health care charges associated with physical inactivity, overweight, and obesity." Prev Chronic Dis **2**(4): A09.

Bancroft, C., S. Joshi, A. Rundle, M. Hutson, C. Chong, C. C. Weiss, J. Genkinger, K. Neckerman and G. Lovasi (2015). "Association of proximity and density of parks and objectively measured physical activity in the United States: A systematic review." Soc Sci Med **138**: 22-30.

Baran, P. K., W. R. Smith, R. C. Moore, M. F. Floyd, J. N. Bocarro, N. G. Cosco and T. M. Danninger (2014). "Park Use Among Youth and Adults: Examination of Individual, Social, and Urban Form Factors." Environ Behav **46**(6): 768-800.

Bedimo-Rung, A., J. Gustat, B. J. Tompkins, J. Rice and J. Thomson (2006). "Development of a direct observation instrument to measure environmental characteristics of parks for physical activity." J Phys Act Health **3**(Supplement 1): S176-S189.

Bedimo-Rung, A. L., A. J. Mowen and D. A. Cohen (2005). "The significance of parks to physical activity and public health: a conceptual model." Am J Prev Med **28**(2 Suppl 2): 159-168.

Beretvas, S. N., J. L. Meyers and R. A. Rodriguez (2005). "The cross-classified multilevel measurement model: an explanation and demonstration." J Appl Meas **6**(3): 322-341.

Berrigan, D., L. W. Pickle and J. Dill (2010). "Associations between street connectivity and active transportation." Int J Health Geogr **9**: 20.

Cao, X., P. L. Mokhtarian and S. L. Handy (2009). "Examining the impacts of residential self-selection on travel behaviour: A focus on empirical findings." Transp Rev **29**(3): 359-395.

Carlson, J. A., J. F. Sallis, T. L. Conway, B. E. Saelens, L. D. Frank, J. Kerr, K. L. Cain and A. C. King (2012). "Interactions between psychosocial and built environment factors in explaining older adults' physical activity." Prev Med **54**(1): 68-73.

Carlson, S. A., J. D. Brooks, D. R. Brown and D. M. Buchner (2010). "Racial/Ethnic differences in perceived access, environmental barriers to use, and use of community parks." Prev Chronic Dis **7**(3): A49.

Cerin, E., E. Leslie, L. du Toit, N. Owen and L. D. Frank (2007). "Destinations that matter: associations with walking for transport." Health Place **13**(3): 713-724.

Cervero, R. and K. Kockelman (1997). "Travel demand and the 3Ds: Density, diversity, and design." Transp Res D Transp Environ **2**(3): 199-219.

Chaix, B., Y. Kestens, D. T. Duncan, R. Brondeel, J. Meline, T. El Aarbaoui, B. Pannier and J. Merlo (2016). "A GPS-Based Methodology to Analyze Environment-Health Associations at the Trip Level: Case-Crossover Analyses of Built Environments and Walking." Am J Epidemiol **184**(8): 570-578.

Cohen, D. A., D. Golinelli, S. Williamson, A. Sehgal, T. Marsh and T. L. McKenzie (2009). "Effects of park improvements on park use and physical activity: policy and programming implications." Am J Prev Med **37**(6): 475-480.

Cohen, D. A., B. Han, K. P. Derose, S. Williamson, T. Marsh and T. L. McKenzie (2013). "Physical activity in parks: A randomized controlled trial using community engagement." Am J Prev Med **45**(5): 590-597.

Cohen, D. A., B. Han, C. J. Nagel, P. Harnik, T. L. McKenzie, K. R. Evenson, T. Marsh, S. Williamson, C. Vaughan and S. Katta (2016). "The First National Study of Neighborhood Parks: Implications for Physical Activity." Am J Prev Med **51**(4): 419-426.

Cohen, D. A., T. Marsh, S. Williamson, D. Golinelli and T. L. McKenzie (2012). "Impact and cost-effectiveness of family Fitness Zones: a natural experiment in urban public parks." Health Place **18**(1): 39-45.

Cohen, D. A., T. L. McKenzie, A. Sehgal, S. Williamson, D. Golinelli and N. Lurie (2007). "Contribution of public parks to physical activity." Am J Public Health **97**(3): 509-514.

Coombes, E., A. P. Jones and M. Hillsdon (2010). "The relationship of physical activity and overweight to objectively measured green space accessibility and use." Soc Sci Med **70**(6): 816-822.

Crompton, J. L. (2001). "The impact of parks on property values: a review of the emperical evidence." J Leis Res **33**(1): 1-31.

Design For Health. (2012). "Environment and Physical Activity GIS Protocols Manual." Retrieved August 13, 2015, from http://designforhealth.net/resources/other/gis-protocols/.

Diez-Roux, A. V. (2000). "Multilevel analysis in public health research." Annu Rev Public Health **21**: 171-192.

Duncan, C., K. Jones and G. Moon (1998). "Context, composition and heterogeneity: using multilevel models in health research." Soc Sci Med **46**(1): 97-117.

Engelberg, J. K., T. L. Conway, C. Geremia, K. L. Cain, B. E. Saelens, K. Glanz, L. D. Frank and J. F. Sallis (2016). "Socioeconomic and race/ethnic disparities in observed park quality." BMC Public Health **16**: 395.

Evenson, K. R., F. Wen, A. Hillier and D. A. Cohen (2013). "Assessing the contribution of parks to physical activity using global positioning system and accelerometry." Med Sci Sports Exerc **45**(10): 1981-1987.

Ewing, R. (1995). "Beyond density, mode choice, and single purpose trips." Transportation Quarterly **49**(4): 15-24.

Floyd, M. F., J. N. Bocarro, W. R. Smith, P. K. Baran, R. C. Moore, N. G. Cosco, M. B. Edwards, L. J. Suau and K. Fang (2011). "Park-based physical activity among children and adolescents." Am J Prev Med **41**(3): 258-265.

Forsyth, A., D. Van Riper, N. Larson, M. Wall and D. Neumark-Sztainer (2012). "Creating a replicable, valid cross-platform buffering technique: the sausage network buffer for measuring food and physical activity built environments." Int J Health Geogr **11**: 14.

Frank, L. D., J. F. Sallis, B. E. Saelens, L. Leary, K. Cain, T. L. Conway and P. M. Hess (2010). "The development of a walkability index: application to the Neighborhood Quality of Life Study." Br J Sports Med **44**(13): 924-933.

Frank, L. D., T. L. Schmid, J. F. Sallis, J. Chapman and B. E. Saelens (2005). "Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ." Am J Prev Med **28**(2 Suppl 2): 117-125.

Giles-Corti, B., M. H. Broomhall, M. Knuiman, C. Collins, K. Douglas, K. Ng, A. Lange and R. J. Donovan (2005). "Increasing walking: how important is distance to, attractiveness, and size of public open space?" Am J Prev Med **28**(2 Suppl 2): 169-176.

Godbey, G. and A. Mowen (2010). The Benefits of Physical Activity Provided by Park and Recreation Services: The Scientific Evidence. National Recreation and Park Association.

Gorman, E., H. M. Hanson, P. H. Yang, K. M. Khan, T. Liu-Ambrose and M. C. Ashe (2014). "Accelerometry analysis of physical activity and sedentary behavior in older adults: a systematic review and data analysis." Eur Rev Aging Phys Act **11**: 35-49.

Gunasekara, F. I., K. Richardson, K. Carter and T. Blakely (2014). "Fixed effects analysis of repeated measures data." Int J Epidemiol **43**(1): 264-269.

Hurvitz, P. M., A. V. Moudon, B. Kang, B. E. Saelens and G. E. Duncan (2014). "Emerging technologies for assessing physical activity behaviors in space and time." Front Public Health **2**: 2.

Jilcott, S. B., K. R. Evenson, B. A. Laraia and A. S. Ammerman (2007). "Association between physical activity and proximity to physical activity resources among low-income, midlife women." Prev Chronic Dis **4**(1): A04.

Kaczynski, A. T., G. M. Besenyi, S. A. Stanis, M. Koohsari, K. B. Oestman, R. Bergstrom, L. R. Potwarka and R. S. Reis (2014). "Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics." Int J Behav Nutr Phys Act **11**(1): 146.

Kaczynski, A. T. and M. E. Havitz (2009). "Examining the Relationship between Proximal Park Features and Residents' Physical Activity in Neighborhood Parks." J Leis Res **27**(3).

Kaczynski, A. T. and A. J. Mowen (2011). "Does self-selection influence the relationship between park availability and physical activity?" Prev Med **52**(1): 23-25.

Kaczynski, A. T., L. R. Potwarka and B. E. Saelens (2008). "Association of park size, distance, and features with physical activity in neighborhood parks." Am J Public Health **98**(8): 1451-1456.

Kaczynski, A. T., S. A. Stanis and G. M. Besenyi (2012). "Development and testing of a community stakeholder park audit tool." Am J Prev Med **42**(3): 242-249.

Kaczynski, A. T., S. A. Wilhelm Stanis, T. J. Hastmann and G. M. Besenyi (2011). "Variations in observed park physical activity intensity level by gender, race, and age: individual and joint effects." J Phys Act Health **8 Suppl 2**: S151-160.

Kang, B., A. V. Moudon, P. M. Hurvitz, L. Reichley and B. E. Saelens (2013). "Walking objectively measured: classifying accelerometer data with GPS and travel diaries." Med Sci Sports Exerc **45**(7): 1419-1428.

Kang, B., J. Y. Scully, O. Stewart, P. M. Hurvitz and A. V. Moudon (2015). "Split-Match-Aggregate (SMA) algorithm: integrating sidewalk data with transportation network data in GIS." Int J Geogr Inf Sci **29**(3): 440-453.

King, W. C., S. H. Belle, J. S. Brach, L. R. Simkin-Silverman, T. Soska and A. M. Kriska (2005). "Objective measures of neighborhood environment and physical activity in older women." Am J Prev Med **28**(5): 461-469.

King, W. C., J. S. Brach, S. Belle, R. Killingsworth, M. Fenton and A. M. Kriska (2003). "The relationship between convenience of destinations and walking levels in older women." Am J Health Promot **18**(1): 74-82.

Krieger, N., D. R. Williams and N. E. Moss (1997). "Measuring social class in US public health research: concepts, methodologies, and guidelines." Annu Rev Public Health **18**: 341-378.

Lackey, K. J. and A. T. Kaczynski (2009). "Correspondence of perceived vs. objective proximity to parks and their relationship to park-based physical activity." Int J Behav Nutr Phys Act **6**: 53.

Leckie, G. (2013). "Cross-Classified Multilevel Models. LEMMA VLE Module 12, 1-60. ." from http://www.bristol.ac.uk/cmm/learning/course.html.

Lee, C. and A. V. Moudon (2006). "Correlates of walking for transportation or recreation purposes." J Phys Act Health **3**(1S): S77–S98.

Lee, C., A. V. Moudon and J.-Y. P. Courbois (2006). "Built Environment and Behavior: Spatial Sampling Using Parcel Data." Ann Epidemiol **16**(5): 387-394.

Lee, J.-H., D. Scott and M. F. Floyd (2001). "Structural Inequalities in Outdoor Recreation Participation: A Multiple Hierarchy Stratification Perspective." J Leis Res **33**(4).

Lee, P. H. (2014). "Should we adjust for a confounder if empirical and theoretical criteria yield contradictory results? A simulation study." Sci Rep **4**: 6085.

Locascio, J. J. and A. Atri (2011). "An overview of longitudinal data analysis methods for neurological research." Dement Geriatr Cogn Dis Extra **1**(1): 330-357.

Lovasi, G. S., L. J. Underhill, D. Jack, C. Richards, C. Weiss and A. Rundle (2012). "At Odds: Concerns Raised by Using Odds Ratios for Continuous or Common Dichotomous Outcomes in Research on Physical Activity and Obesity." Open Epidemiol j **5**: 13-17.

Masse, L. C., B. F. Fuemmeler, C. B. Anderson, C. E. Matthews, S. G. Trost, D. J. Catellier and M. Treuth (2005). "Accelerometer data reduction: a comparison of four reduction algorithms on select outcome variables." Med Sci Sports Exerc **37**(11 Suppl): S544-554.

McConville (2009). Defining Mixed-use: Which Land Uses Promote Walking?

McCormack, G. R., B. Giles-Corti and M. Bulsara (2008). "The relationship between destination proximity, destination mix and physical activity behaviors." Prev Med **46**(1): 33-40.

Moudon, A. V., A. J. Cook, J. Ulmer, P. M. Hurvitz and A. Drewnowski (2011). "A neighborhood wealth metric for use in health studies." Am J Prev Med **41**(1): 88-97.

Moudon, A. V., A. Drewnowski, G. E. Duncan, P. M. Hurvitz, B. E. Saelens and E. Scharnhorst (2013). "Characterizing the food environment: pitfalls and future directions." Public Health Nutr **16**(7): 1238-1243.

Moudon, A. V., C. Lee, A. D. Cheadle, C. Garvin, D. B. Rd, T. L. Schmid and R. D. Weathers (2007). "Attributes of environments supporting walking." Am J Health Promot **21**(5): 448-459.

Moudon, A. V., B. E. Saelens, S. Rutherford and M. Hallenbeck. (2009). "A Report on Participant Sampling and Recruitment for Travel and Physical Activity." Retrieved May 05, 2014, from http://ntl.bts.gov/lib/31000/31700/31738/VernezMoudon_EffectofLight_Rail.pdf.

National Oceanic and Atmospheric Administration. "Global Historical Climatology Network-Daily." Retrieved August 01, 2014, from http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/.

Physical Activity Guidelines Advisory Committee (2008). Physical Activity Guidelines Advisory Committee Report 2008. Washington, DC, Department of Health and Human Services.

Pratt, M., C. A. Macera and G. Wang (2000). "Higher direct medical costs associated with physical inactivity." Phys Sportsmed **28**(10): 63-70.

Rodriguez, D. A., K. R. Evenson, A. V. Diez Roux and S. J. Brines (2009). "Land use, residential density, and walking. The multi-ethnic study of atherosclerosis." Am J Prev Med **37**(5): 397-404.

Rundle, A., J. Quinn, G. Lovasi, M. D. M. Bader, P. Yousefzadeh, C. Weiss and K. Neckerman (2013). "Associations Between Body Mass Index and Park Proximity, Size, Cleanliness, and Recreational Facilities." Am J Health Promot **27**(4): 262-269.

Saelens, B. E., L. D. Frank, C. Auffrey, R. C. Whitaker, H. L. Burdette and N. Colabianchi (2006). "Measuring physical environments of parks and playgrounds: EAPRS instrument development and inter-rater reliability." J Phys Act Health **3**(Supplement 1): S190-S207.

Saelens, B. E., J. F. Sallis, L. D. Frank, K. L. Cain, T. L. Conway, J. E. Chapman, D. J. Slymen and J. Kerr (2012). "Neighborhood environment and psychosocial correlates of adults' physical activity." Med Sci Sports Exerc **44**(4): 637-646.

Sallis, J. F. (2009). "Measuring physical activity environments: a brief history." Am J Prev Med **36**(4 Suppl): S86-92.

Sallis, J. F., M. F. Floyd, D. A. Rodriguez and B. E. Saelens (2012). "Role of built environments in physical activity, obesity, and cardiovascular disease." Circ **125**(5): 729-737.

Sallis, J. F. and B. E. Saelens (2000). "Assessment of physical activity by self-report: status, limitations, and future directions." Res Q Exerc Sport **71**(2 Suppl): S1-14.

Schipperijn, J., P. Bentsen, J. Troelsen, M. Toftager and U. K. Stigsdotter (2013). "Associations between physical activity and characteristics of urban green space." Urban Forestry & Urban Greening **12**(1): 109-116.

Shores, K. A. and S. T. West (2008). "The relationship between built park environments and physical activity in four park locations." J Public Health Manag Pract **14**(3): e9-16.

Stewart, O. T., H. A. Carlos, C. Lee, E. M. Berke, P. M. Hurvitz, L. Li, A. V. Moudon and M. P. Doescher (2016). "Secondary GIS built environment data for health research: Guidance for data development." J Transp Health **3**(4): 529-539.

Stewart, O. T., A. V. Moudon, M. D. Fesinmeyer, C. Zhou and B. E. Saelens (2016). "The association between park visitation and physical activity measured with accelerometer, GPS, and travel diary." Health Place **38**: 82-88.

Stewart, O. T., A. Vernez Moudon, B. E. Saelens, C. Lee, B. Kang and M. P. Doescher (2016). "Comparing Associations Between the Built Environment and Walking in Rural Small Towns and a Large Metropolitan Area." Environ Behav **48**(1): 13-36.

Strath, S. J., M. J. Greenwald, R. Isaacs, T. L. Hart, E. K. Lenz, C. J. Dondzila and A. M. Swartz (2012). "Measured and perceived environmental characteristics are related to accelerometer defined physical activity in older adults." Int J Behav Nutr Phys Act **9**: 40.

Sugiyama, T., J. Francis, N. J. Middleton, N. Owen and B. Giles-Corti (2010). "Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces." Am J Public Health **100**(9): 1752-1757.

Taylor, B. T., P. Fernando, A. E. Bauman, A. Williamson, J. C. Craig and S. Redman (2011). "Measuring the quality of public open space using Google Earth." Am J Prev Med **40**(2): 105-112.

Tester, J. and R. Baker (2009). "Making the playfields even: evaluating the impact of an environmental intervention on park use and physical activity." Prev Med **48**(4): 316-320.

Troiano, R. P., D. Berrigan, K. W. Dodd, L. C. Masse, T. Tilert and M. McDowell (2008). "Physical activity in the United States measured by accelerometer." Med Sci Sports Exerc **40**(1): 181-188.

US Department of Health and Human Services. (2008). "2008 physical activity guidelines for Americans." Retrieved February 25, 2014, from http://www.health.gov/paguidelines/guidelines/default.aspx.

US National Physical Activity Plan Coordinating Committee. (2010). "National Physical Activity Plan." Retrieved September 23, 2013, from http://www.physicalactivityplan.org/NationalPhysicalActivityPlan.pdf.

Van Dyck, D., J. F. Sallis, G. Cardon, B. Deforche, M. A. Adams, C. Geremia and I. De Bourdeaudhuij (2013). "Associations of neighborhood characteristics with active park use: an observational study in two cities in the USA and Belgium." Int J Health Geogr **12**: 26-26.

Veitch, J., K. Ball, D. Crawford, G. R. Abbott and J. Salmon (2012). "Park improvements and park activity: a natural experiment." Am J Prev Med **42**(6): 616-619.

Weng, H. Y., Y. H. Hsueh, L. L. Messam and I. Hertz-Picciotto (2009). "Methods of covariate selection: directed acyclic graphs and the change-in-estimate procedure." Am J Epidemiol **169**(10): 1182-1190.

Wieters, K. M. (2009). "Integrating Walking for Transportation and Physical Activity for Sedentary Office Workers in Texas." from https://repository.tamu.edu/bitstream/handle/1969.1/ETD-TAMU-2009-08-6988/WIETERS-DISSERTATION.pdf?sequence=3.

Zanon, D., J. Hall, L. Lockstone-Binney and D. Weber (2014). "Development of a Whole Agency Approach to Market Segmentation in Parks." J Leis Res **46**(5): 563-592.

Zhang, X., H. Lu and J. B. Holt (2011). "Modeling spatial accessibility to parks: a national study." Int J Health Geogr **10**: 31.

Zou, G. (2004). "A modified poisson regression approach to prospective studies with binary data." Am J Epidemiol **159**(7): 702-706.