Published in final edited form as:

Health Place. 2011 January ; 17(1): 207–214. doi:10.1016/j.healthplace.2010.10.001.

Childhood obesity and proximity to urban parks and recreational resources: A longitudinal cohort study

Jennifer Wolch^{a,*}, Michael Jerrett^b, Kim reynolds^c, Rob McConnell^d, Roger Chang^d, Nicholas Dahmann^d, Kirby Brady^e, Frank Gilliland^d, Jason G. Su^b, and Kiros Berhane^d

^aCollege of Environmental Design, University of California, Berkeley, 230 Wurster Hall #1820, Berkeley, CA, 94720-1820

^bEnvironmental Health Sciences, School of Public Health, University of California, Berkeley, Berkeley, CA 94720-7360

^cDepartment of Preventive Medicine, School of Community & Global Health, Claremont Graduate University, San Dimas, CA 91773

^dDepartment of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, CA 90089-9031

^eCenter for Sustainable Cities, College of Letters, Arts, and Sciences, University of Southern California, Los Angeles, CA 90089-4012

Abstract

The objective of the research was to assess how proximity to parks and recreational resources affects the development of childhood obesity through a longitudinal study. Data were collected on 3173 children aged 9–10 from 12 communities in Southern California in 1993 and 1996. Children were followed for eight years to collect longitudinal information, including objectively measured body mass index (BMI). Multilevel growth curve models were used to assess associations between attained BMI growth at age 18 and numerous environmental variables, including park space and recreational program access. For park acres within a 500 meter distance of children's homes, there were significant inverse associations with attained BMI at age 18. Effect sizes were larger for boys than for girls. Recreation programs within a 10 km buffer of children's homes were significantly and inversely associated with achieved levels in BMI at age 18, with effect sizes for boys also larger than those for girls. We conclude that children with better access to park and recreational resources are less likely to experience significant increases in attained BMI.

Keywords

obesity; built environment; parks and recreation; GIS; multilevel growth curve models

© 2010 Elsevier Ltd. All rights reserved.

*Corresponding author: Tel.: +1 5106420831; Fax: +1 5106427560. wolch@berkeley.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1. Introduction

Obesity is a serious and worsening public health problem. The occurrence of overweight risk and high body mass index (BMI) status in youth age 2–19 years increased to approximately 32% by 2003–2006, up from approximately 15% in the 1970's (Ogden et al., 2008). Obesity can be detrimental to children's health, increasing risk of type 2 diabetes, cardiovascular disease, and additional physical or psychological problems (Dietz, 1998). Additionally, overweight children and adolescents are more likely to become overweight adults (Freedman et al., 2007). Many potential explanations exist addressing the root causes of the obesity problem. While genetic factors probably contribute (Stunkard, 1991), rapid increases in obesity suggest that individual behavior patterns including low levels of physical activity appear to powerfully influence obesity trends (Hill and Peters, 1998).

The urban built environment, including parks and other green space, and recreation programs that provide structured settings for exercise, might also shape opportunities for physical activity, affecting development of obesity. Research suggests that physical characteristics of the built environment surrounding a child's neighborhood or school can significantly influence physical activity and thus health outcomes (Sallis et al., 1997; Cummins and Jackson, 2001; Godbey et al., 2003; Ho et al., 2003; Godbey et al., 2005). Parks especially have been investigated (Bedimo-Rung et al., 2005), while recreational programming has been infrequently studied for either adults or children (Dahmann et al., 2010).

Leisure researchers established the benefits of parks from social, psychological, and environmental standpoints but recent public health studies focus on the role of parks in promoting physical activity (Sallis et al., 1992; Cummins and Jackson, 2001). Several studies have specifically examined relationships between parks and children's physical activity (Sallis et al., 2000; Krizek et al., 2004). Many show that children with more access to parks and recreational facilities are more active than children with less access (Sallis et al., 1992; Gomez et al., 2004; Timperio et al., 2004). Measures used in such research include presence vs. absence of a park or recreation facility near the home, density of facilities, or total acreage of recreational land within a given radius of the home (Mota et al., 2005; Norman et al., 2006; Roenmich et al., 2006). A few studies (Sallis et al., 1999; Pate et al., 2002) using accelerometry to measure physical activity objectively, as opposed to self-report or direct observation that might be subject to bias (Davison and Lawson, 2006), reported no link between physical activity and environmental variables including access to parks.

Giles-Corti et al. (2005) outlined the importance of attractiveness and size of open space in addition to access and proximity. In a series of studies (Giles-Corti et al., 2003; Giles-Corti and Donovan, 2002), associations between environmental factors and physical activity were examined in a sample of adults age 18–59 in Perth, Australia. Using cross-sectional surveys and a scan of environmental facilities, these studies adjusted for demographics and variations in the built environment (e.g. absence vs. presence of sidewalks, access to recreational facilities). They reported that parks were more likely to encourage physical activity if they were perceived as aesthetically pleasing (minor traffic, sidewalks, trees, retail shops).

Only a handful of studies have objectively measured environmental characteristics such as parks or recreational resources, to understand their association with obesity in children or youth. Methodological issues of concern include the use of varying measurements and the limiting nature of the cross-sectional design. In a cross-sectional study, for example, Kligerman et al. (2006) used a 4-component neighborhood walkability index (that reflected the quality of pedestrian facilities, roadway conditions, land use patterns, and community support, security and comfort for walking), and access/proximity to recreation facilities as determinants of physical activity and obesity in adolescents as measured by BMI, finding that BMI was not significantly related to these environmental variables (Kligerman et al., 2007). Norman et al. (2006), employing similar measures, also reported a lack of significant relationships between BMI and the built environment variables, as did Liu et al. (2006) and Burdette and Whitaker (2003), using somewhat different built environment measures. Gordon-Larsen and colleagues (2006), in contrast, used distance to nearest physical activity facility in a sample of 7th to 12th grade adolescents to determine relationships between recreational facility proximity and obesity, finding significant links between absence or reduced access to facilities, decreased physical activity, and increased obesity in low socioeconomic status and high minority neighborhoods.

Publicly-provided recreational programming is among the least studied determinant of physical activity and childhood obesity. Dahmann et al. (2010), in a cross-sectional study, audited recreation programs from southern California municipalities, finding that areas with higher population density, lower incomes, and a greater share of minority residents had inferior access to public recreational programming; but this study did not relate the distribution of recreational resources to either physical activity or obesity.

To assess the influence of parks and recreation, it is also necessary to include control for built environment variables that may be associated with the BMI and recreation programs or parks. The literature points to a wide range of factors in the built environment that may influence cardio-metabolic outcomes including obesity (Leal and Chaix 2010). Dietary intake has direct links to obesity and might be associated with the availability of food resources such as supermarkets, restaurants, and fast-food outlets, along with family influences that may themselves be grounded in class, race/ethnicity and cultural background (Charreire et al. 2010). Built environmental characteristics related to pollution exposure can be directly linked to the onset of acute and chronic health conditions such as asthma that limit physical activity (Jerrett et al. 2009; McConnell et al. 2010). Recent studies have also identified traffic density as a potential risk factor for obesity formation in children (Jerrett et al. 2010). Finally, the social conditions, such as poverty and unemployment, as well as crime, may also negatively influence park use and recreational program utilization and be related to obesity (Dahmann et al 2010). In assessing the influence of parks and recreational programming, these variables must be taken into account in the modeling strategy.

2. Methods

We hypothesize that parklands and recreation programs are related to longitudinal obesity outcomes in children. To test this hypothesis, we developed a comprehensive inventory of recreation programming for a large cohort of children as well as an extensive array of other

built environment, household and individual variables that may confound associations between parks or recreational programming and BMI growth in children . We utilized advanced multilevel growth curves to assess the associations between access to parks and to recreation programs, and obesity in children aged 10–18 years.

2.1 Study design

As part of the Southern California Children's Health Study (CHS), a cohort of 3173 children aged 9–10 from 12 communities in Southern California were enrolled in 1993 and 1996 to assess associations between respiratory health and environmental factors. Details on the design, site selection, subject recruitment and assessment of health effects were reported elsewhere (Navidi et al., 1994). At baseline, a parent/guardian of each participating child provided written informed consent and completed a written questionnaire on demographics, history of respiratory illness and associated risk factors, indoor exposure sources, physical activity, and household characteristics. Each spring an update questionnaire was completed by each child, and pulmonary function test measures were obtained along with physiologic measures such as height and weight.

Every subject had height and weight measured by a trained technician at baseline and annually through the 8-year follow-up. Two-person technician teams followed a standardized protocol, using torpedo levels to accurately measure height and routine weight scale calibration procedures, procuring accurate measures of BMI as kg of weight/height squared in m. The built-environment measures of interest, namely parklands, and recreation programs/facilities around the children's homes and schools, were derived from buffer analysis using the Arc 9.2 Geographic Information System (ESRI Redlands, CA). These features were linked to each child's BMI and individual questionnaire data based on the children's home addresses. Physical features (e.g., elevation) and social environment variables (e.g., poverty in the census block of residence) were also collected as potential confounders (see Jerrett et al. 2010 for more detail on variable construction and the variables tested). Home locations were geocoded using the Teleatlas geocoding database to the corresponding road network. The research protocol was approved by the Institutional Review Board of the University of Southern California and the University of California, Berkeley.

2.2 Characteristics of study communities

The study area communities are heterogeneous in terms of size, social dimensions, urban form, and environmental characteristics as well as racial composition, household income, crime, poverty and unemployment rates. Communities vary from low-density suburbs to higher density, older urban centers. Communities also vary in terms of walkability, impervious hardscape (such as concrete sidewalks, paved plazas, parking lots or roadway pavement) and green cover in the form of shrubs, grasses and trees. The CHS communities enjoy very different parkland and recreational program resources; three communities offer little/no recreational programming (Figures 1 and 2).

2.3 Measures of the built environment

We organized an array of GIS variables to characterize the urban environment of study communities (Jerrett et al., 2010). These included both built environment measures (such as street pattern, traffic, and uses, green cover, and so on), and measures of the socio-economic environment (including poverty, unemployment, demographics, and crime rates). Some measures were at the town level, while others characterized the immediate neighborhoods around children's homes and schools, either by using census block group data or buffers. Unless otherwise noted, buffer variables were tested with 500 m Euclidian buffers (Jerrett et al., 2010). Variables at smaller radii indicated that some features had limited data available below 500 m, while larger radii buffers beyond 500 m tended to diminish the effect sizes.

Park space (in acres) was measured around the children's home with a 500 m buffer (roughly a quarter mile distance), a distance that provides easy access (10–15 minutes of travel time) for children going to a park on foot or bike (Dill 2004; Wolch et al., 2005). Only the area within the buffer distance was included. We also tested both smaller (250 meter) and larger (750 and 1000 meter) buffers; the former were unstable in terms of model performance, and the latter had less predictive power. While small parks tend to be used more often by children, the small and large parks were found to have similar frequency of usage by adolescents (Grow et al., 2008). Parents may provide more car transportation for their adolescents to team sports or other structured activities at sports facilities such as facilities in large parks, which may be farther from home. The spatial distribution of public parks in the study region is shown in Figure 3. Four datasets were used to characterize land use such as parks (as well as to understand the distribution of residential, industrial and commercial land uses). As most study participants resided in the Southern California Association of Governments (SCAG) area, the SCAG land use classification system, with 13 main categories, was used as the standard. Three other classification systems were used after careful harmonization of their classification systems with the SCAG classifications: the San Diego Association of Governments, the Santa Barbara Assessor's office, and the City of Atascadero. Definitions of parks were reasonably uniform across datasets.

2.4 Measures of recreational programming

While parks are often the venue for recreation programs, such programs are also offered at stand-alone recreation centers and even in nonprofit sports centers under municipal auspices, and numbers of programs per venue ranges widely, making simple access measures a poor estimate of this potentially beneficial exposure (Dahmann et al., 2010). We thus computed the number of municipal recreation programs targeted to those under 18 and involving some level of physical exertion, available within 5 and 10 kilometer buffers of children's homes, for inclusion in our modeling framework.

Recreational programming data were collected by means of an audit of public recreation courses performed during the summer 2006. Recreational offerings were gathered from municipal park and recreation brochures and materials. Most data were collected via internet search and validated through telephone contact, mailings and ground truthing. A focus was placed specifically on formally organized recreation opportunities. Recreational course offerings needed to be sponsored by either the municipality or a non-profit organization, be

offered at a city-owned facility or held at a non-city owned site but yet still be sponsored by the city. For each recreation course meeting the criteria, we recorded location, type of activity, frequency of the program, age group, gender, enrollment size, capacity, and cost. If a program was sponsored by a non-profit organization, the name of the organization and whether the program was conducted independently of the city were further recorded.

Data were collected for 96 municipalities, primarily located in Los Angeles County, with a portion located in Orange and Ventura counties. Course durations were grouped at natural breaks by 6 categories: Less than 30 minutes, 30 to 60 minutes, 61 to 90 minutes, 91 to 180 minutes, greater than 180 minutes, and missing. Similarly, targeted age was also classified into 6 groups: 0–5, 5–18, 18–50, 50+, all ages, and missing. Each listing for sports, fitness, or other recreation programs that required a metabolic equivalent (MET) value greater than 3.5 (physical exertion equivalent to moderate walking) was included in the database. We focused on recreational programming, instead of simple measures of access to parks or recreational facilities, because of our interest in understanding how active recreation per se was linked to the development of obesity in children. Addresses were geocoded in ESRI ArcView 9.2 and verified with Teleatlas. Only programs that were age appropriate to children and adolescents were included in the summation (for example, programs for senior citizens were excluded). With 8 years of follow up for BMI and other information, the application of summer 2006 recreation data might introduce some temporal mismatch errors; however, we assumed most of the communities were relatively well-established and recreational programming would be relatively stable year-to-year. Errors in the exposure to recreational programs due to this temporal mismatch would likely be non-differential and as such would bias our effect estimates toward the null.

2.5 Data analysis

We used a multi-level growth curve model that employed a flexible linear-spline based approach to characterize the nonlinear BMI trajectories during childhood. Similar models have been used for assessing lung function growth in our cohort and were adapted for BMI growth (Gauderman et al., 2007). All BMI data were checked for outliers and internal consistency in the growth curves. We assessed separate gender-specific growth trajectories and combined models for both sexes. This approach allowed for examination of the effects of covariates of interest at various levels: between times (within individual), between individuals and between other levels of aggregation (e.g., school, neighborhood, town, etc.). Gender-specific BMI trajectories were estimated using linear splines with breakpoints at ages 12, 14 and 16, essentially fitting four straight lines for 9–12, 12–14, 14–16 and 16–19 yrs of age and joining them smoothly at the knots to provide nonlinear growth trajectories. The modeled trajectories predict BMI levels for any age group between 9 and 19. In this analysis attained BMI levels at age 18 were used as an example to identify their association with explanatory variables.

Many individual risk factors for BMI growth such as asthma and other respiratory conditions, individual and neighborhood/community level socio-economic indicators, smoking (both personal and second hand smoke), and numerous built environment variables around the home and school were also tested as confounders.

The final models were developed by including all additional confounders that (a) had a significant bivariate association with BMI growth and (b) changed the effect of interest – parkland and recreational programming access – by at least 10% in either of the gender specific effects (see Jerrett et al. 2009 or McConnell et al. 2010 for similar approaches to confounding screening). In addition, we manually selected variables within substantive categories of built environment characteristics to prevent redundancy and avoid collinearity. Equality between gender-specific effects of built-environment factors was tested via appropriate interaction terms for gender related differences. Significance was based on a 0.05 level of significance for a two-sided hypothesis. All analyses were conducted by using the SAS (SAS Institute Inc., Cary, NC) and/or R (R Foundation for Statistical Computing, Vienna, Austria) statistical software packages. Data were compiled using ArcGIS 9.2 (ESRI, Redlands, CA) and some distance measurements were computed using Matlab v.R2006a (The Mathworks, Natick, MA).

3 Results

The cohort included 3173 children after data cleaning and elimination of outliers and missing values. Table 1 shows their BMI z-scores based on the Center for Disease Control classifications, showing variations across race, ethnicity and gender.

The number of recreation programs accessible within 5 and 10 km buffers varied markedly from place to place. Access of children to programs within 5 km of their home was so limited that we focused exclusively on accessibility within 10 km (Figure 4) for modeling purposes.

Based on screening for confounding variables, models were tested with two main effects: acres of parkland within a 500 m buffer of the child's home, and the number of public recreation programs offered within a 10 km buffer of the home. The parkland model included a series of confounders (Table 2), the most important of which were traffic density within a 150 m buffer of the child's home (Jerrett et al., 2010), average urban imperviousness and normalized difference vegetation index 'greenness' values within 500 m of the home; total arterial (or high volume) road length within the 500 m buffer; number of 'X' intersections with the buffer (a measure of connectivity), and percent of population living below poverty within the residence's census block group. The recreation programs model had all of these confounders, as well as total population within the 500 m buffer around the home; the distance between the child's residence and the nearest highway; average tree canopy within the 500 m residence buffer; acres of agricultural land use and buffer population density within 500 m; and town level forcible rape rate per 100,000 as an indicator of violent crime. Of the 140 or so confounders tested, these were the only ones that met our inclusion criteria. All models also included design variables for race or ethnicity, gender, cohort or enrollment, and a random effect for town.

Results for both models, shown in Table 4, indicated that access to both parkland and recreation programs reduce risk of overweight and obesity as measured by BMI attained at age 18. Gender differences were notable but significant only for access to recreation. When evaluated against the 10–90th percentile exposure contrast for each variable, the effects sizes

for access to recreation programming were much larger than those for parkland access. The effect on attained male BMI was about -0.19 units and for females about -0.1 units over the 10–90 percentile range of 14.82 programs. The combined estimate for males and females was about -0.14 BMI units for access to parkland. In contrast the effect of recreational programming was about 10 times greater across the 10–90 percentile exposure contrast of 82 programs, i.e., -1.87 BMI units for males, -1.1 for females with a combined estimate of -1.4 .

As expected, the confounders diminished the strength of the relationships. Most confounders in the parkland model lowered effect sizes (up to 35.4%), but relationships between parks and BMI remained significant and negative. The largest changes in effect sizes for both genders were due to: (1) inclusion of walkability measures (traffic, density of arterial roadways, 'X' intersections), which increased or maintained the protective effect of parks for boys, while lowering it somewhat for girls. This is consistent with other studies suggesting that walking environment may have a greater impact on girls (Navidi et al., 1994); (2) imperviousness and green cover (NDVI), which decreased parkland effect sizes for both genders – predictable since these variables to some extent reflect abundance of parkland; and (3) neighborhood poverty, which was associated with reduced effect sizes for boys.

Some confounders tended to increase effect sizes but differentially by gender, often with larger increases for boys. Again, adjusting for traffic density and distance from a freeway increased the magnitude of the association for boys, while the freeway variable decreased coefficients for girls. Here, adjusting for other walkability measures increased the magnitude of the associations for girls, as might be expected. Adjusting for urban imperviousness and green cover, as well as agricultural land use reduced effect sizes across genders. Adding poverty was a positive confounder for boys and girls.

Model results were highlighted by considering the change in overweight and obesity rates if all children in the sample were to have commensurate (or average) access to parkland and recreation programs near their homes. Under this scenario, over 9.5% of boys would move from overweight to normal, and 2.6% would move from obese to overweight; for girls, the comparable shifts are 8.3% and 2.1%. Making access to parkland commensurate would move between 1.5 to almost 2% of children sampled from overweight to normal – a smaller but important implication for children's health.

4. Discussion and conclusions

The longitudinal analysis reveals the significant effect of parkland and publicly-provided recreation programs on attained BMI in a large cohort of children living in the 12 Southern California communities. Our research found almost 20% of these children had no access to recreation programs within 10 km, and over a third had no access within 5 km. Many children had very poor access to local parkland; over half had no park within 500 m of their homes.

This study breaks new ground, being the first to consider the impact of public recreation programs on obesity, compared to park access, in a longitudinal analysis of adolescence. The longitudinal design is critical to understanding relationships between obesity trajectories and the built environment/recreational programming, and helps overcome self-selection problems that typify cross-sectional research. Although families in our cohort may have initially moved to a particular home to be close to parks or recreation centers, our results capture the sustained influence of park and recreational proximity on obesity. The longitudinal design reduces the possibility of our effects being entirely due to selection bias where otherwise active families would locate into neighborhood that supported their healthy lifestyle. Through the longitudinal models, we have demonstrated a sustained effect of parks and recreational programming because the initial baseline BMI was controlled in our model. Thus while selection bias is still a possibility, we have demonstrated a sustained effect of the environment that is not solely due to move in of healthy active people to neighborhoods that support and promote physical activity, as could be the case in cross-sectional studies. Lastly, the models also controlled for many confounders at multiple levels, clearly distinguishing the influence of parkland and recreational program access. Though BMI at age 18 was used as an example to demonstrate these effects, the longitudinal study could also be used to detect those effects for age groups between 9 and 18.

Multicollinearity is not easily addressed in this multilevel modeling framework. There are no readily available tests that can simultaneously diagnose multicollinearity and account for the hierarchical clustered structure of the data. We did examine correlations among the variables and did not find any that were higher than 0.64 in bivariate correlations, suggesting sufficient independent variance to estimate stable effects (i.e., below Klein's of thumb of 0.7 r as being acceptable, meaning at least half the variance is free to be associated with the dependent variable). In fact, parks and NDVI had only a 0.35 correlation and with tree canopy the corresponding correlation was only 0.08.

Several limitations should be noted and addressed in future research. First, neither private recreational space such as backyards, nor private recreation programs (for example, at gyms), were included although such opportunities could influence obesity trajectories. Second, longitudinal information on dietary intake was not examined, but is likely to be a direct influence on attained BMI at age 18. Third, we assumed the relative stability of the recreation programs in public parks during the 8 years, some of which might change over time. Changes in the offerings of programs over this time may have introduced measurement error in our estimates, which may have attenuated the effects of recreation programs on BMI growth. However, most of the communities were relatively well-established and unlikely to change the recreational offerings over the period of study. In addition, we used circular buffers rather than network buffers to define the scope of influence. Network buffers might exert a more nuanced effect but would not be expected to generate a significant change in the results. The addition of geographic weighting techniques (Yang, Wu et al. 2009) might also provide more accurate estimates, and is something that should be considered in future research.

A number of prevention recommendations emerge from our results. First, the influence of access to public recreation programs on attained BMI at age 18 was large. The size of the

effect was about 1.5 BMI attained units over the 10–90 percentile of the 10 km recreational program distribution. Where all children in the sample to have commensurate access to recreational programming, between 8–9 percent would move from overweight to normal and 2–3 percent from obese to overweight. Interventions designed to improve access to varied, age-appropriate programs close to home may be extremely important. Such programs could be offered at existing public and nonprofit facilities as well as at schools, increasing accessibility and lowering costs of provision, especially compared to the construction of new, dedicated recreation facilities.

Second, although increasing parkland has less impact on obesity development than provision of public recreation programs, and typically involves capital outlays and maintenance costs, attention to expanding park access is clearly important. Moreover, given that green cover confounds the effect of park access on BMI, investments in parkways, street trees, and other forms of green cover that promote walking, jogging, biking, and informal play appear warranted, and thus partially (although incompletely) substitute for new parklands in terms of their effect on physical activity. This is an important strategy for built-out cities with limited opportunities for new parkland acquisition that could complement additional recreational programming.

Third, walkability is important. Access to parks and recreation programs is effectively reduced by heavy traffic and dense arterial networks cutting through residential areas; the role of street network connectivity is somewhat ambiguous and deserves further research. Nonetheless, results suggest the utility of traffic calming measures, crossing guard programs, and safe routes to park/recreation facilities in urban design and planning.

Lastly, in many metropolitan regions, local per capita public expenditures on parks and recreation range widely; Joassart-Marcelli (Joassart-Marcelli, in review) found that in the poorest southern California communities, less than \$80 per capita was spent, compared to affluent communities which spent almost \$140 per capita. Given the importance of park and public recreation programs to obesity development, a critical prevention strategy is to increase access for children in poorer communities such as the Urban Park and Recreation Recovery Act (UPARR, 1978) and the Land and Water Conservation Fund Act (LWCRA, 1965).

Acknowledgements

This study is supported by NCI Centers for Transdisciplinary Research on Energetics and Cancer (TREC) (U54 CA 116848), the Robert Wood Johnson Foundation Grant (57279), the National Institute of Environmental Health Sciences (5P30 ES007048, 5P01ES011627, R01 ES016535), the National Institute of Health Grant (5R01CA123243-03), the U. S. Environmental Protection Agency (R831845), and the Hastings Foundation. We acknowledge Mr. Bernardo Beckerman for assistance with preparing geographic data and with editing the paper.

References

- BedimoRung A, Mowen J, Cohen D. The significance of parks to physical activity and public health: A conceptual model. *Am J Prev Med.* 2005; 28:159–168. [PubMed: 15694524]
- Burdette HL, Whitaker RC. Neighborhood playgrounds, fast food restaurants, and crime: relationships to overweight in low-income preschool children. *Am J Prev Med.* 2003; 38:57–63.

- Charreire H, Casey R, Salze P, Simon C, Chaix B, Banos A, et al. Measuring the food environment using geographical information systems: a methodological review. *Public Health Nutr.* 2010; 4:1–13.
- Cummins SK, Jackson RJ. The built environment and children's health. *Pediatr Clin North Am.* 2001; 48:1241–1252. [PubMed: 11579672]
- Dahmann N, Wolch J, Joassart-Marcelli P, Reynolds K, Jerrett M. The active city: recreation programs, public health and environmental justice. *Health and Place.* In press.
- Davison KK, Lawson CT. Do attributes in the physical environment influence children's physical activity? A review of the literature. *Int J Behav Nutr Phys Act.* 2006; 19(3)
- Dietz WH. Health consequences of obesity in youth: Childhood predictors of adult disease. *Pediatrics.* 1998; 1998:518–525. [PubMed: 12224658]
- Dill, J. Measuring network connectivity for bicycling and walking. *Transportation Research Board Annual Meeting; Washington, D.C..* 2004.
- Freedman DS, Mei Z, Srinivasan SR, Berenson GS, Dietz WH. Cardiovascular risk factors and excess adiposity among overweight children and adolescents: The Bogalusa heart study. *Pediatrics.* 2007; 150:12–17.
- Gauderman WJ, Vora H, McConnell R, Berhane K, Gilliland F, Thomas D, Lurmann F, Avol E, Kunzli N, Jerrett M, Peters J. Effect of exposure to traffic on lung development from 10–18 years of age: a cohort study. *The Lancet.* 2007; 369:571–577.
- Giles-Corti B, Broomhall MH, Knuiman M, Collins C, Douglas K, Ng K, Lange A, Donovan RJ. Increasing walking: how important is distance to, attractiveness, and size of public open space. *Am J Prev Med.* 2005; 28(2):169–176. [PubMed: 15694525]
- Giles-Corti B, Donovan RJ. The relative influence of individual, social and physical environment determinants of physical activity. *Soc Sci Med.* 2002; 54:1793–1812. [PubMed: 12113436]
- Giles-Corti B, Macintyre D, Clarkson JP, Pikora T, Donovan RJ. Environmental factors associated with overweight and obesity in Perth, Australia. *Am J Health Promot.* 2003; 18:93–102. [PubMed: 13677967]
- Godbey GC, Caldwell LL, Myron F, Payne L. Contributions of leisure studies and recreation and park management to the active living agenda. *Am J Prev Med.* 2005; 28:150–158. [PubMed: 15694523]
- Godbey, GC.; Mowen, AJ. *Franklin County Healthier Communities Through Active Living Summit.* Kauffman Station PA: 2003. The role of parks and recreation in promoting physical activity and health.
- Gomez JE, Johnson BA, Selva M, Sallis JF. Violent crime and outdoor physical activity among inner-city youth. *Am J Prev Med.* 2004; 39:876–881.
- Gordon-Larsen P, Nelson MC, Page P, Popkin BM. Inequality in the built environment underlies key health disparities in physical activity and obesity. *Pediatrics.* 2006; 117:417–424. [PubMed: 16452361]
- Grow HM, Saelens BE, Kerr J, Durant NH, Norman GJ, Sallis JF. Were are youth active? Roles of proximity, active transport, and built environment. *Med. Sci. Sports & Exerc.* 2008; 40:2071–2079. [PubMed: 18981942]
- Hill J, Peters J. Environmental contributions to the obesity epidemic. *Science.* 1998; 280:1371–1374. [PubMed: 9603719]
- Ho C, Payne L, Orsega-Smith E, Godbey G. Parks, recreation and public health. *Parks and Recreation.* 2003; 38:18–27.
- Jerrett M, McConnell R, Wolch J, Chang R, Berhane K. Food Access Around the Home and Growth in the Body Mass Index of Children Aged 10–18 Years: A Longitudinal Cohort Study. *Epidemiology.* 2009; 20(6):S223–S223.
- Jerrett M, McConnell R, Chang R, Wolch J, Reynolds K, Lurmann F, Gilliland F, Berhane K. Automobile traffic around the home and development of obesity in children aged 10–18 years: a longitudinal cohort study. *Preventive Medicine.* 2010; 50:S50–S58. [PubMed: 19850068]
- Joassart-Marcelli P. Leveling the playing field? Urban disparities in funding for local parks and recreation. *Professional Geographer.* In Review.
- Keating KJ. Correlates of vigorous exercise in a predominantly low ses and minority high school population. *Am J Prev Med.* 1994; 23:314–321.

- Kligerman M, Sallis JF, Ryan S, Lawrence F. Association of neighborhood design and recreational environmental variables with physical activity and body mass index in adolescents. *Am J Health Promot.* 2007; 21:274–277. [PubMed: 17375494]
- Krizek K, Birnbaum A, Levinson DM. A schematic for focusing on youth in investigations of community design and physical activity. *Am J Health Promot.* 2004; 19:33–38. [PubMed: 15460099]
- Leal C, Chaix B. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. *Obes Rev.* 2010; 1:1–14.
- Liu GC, Wilson JS, Qi R, Ying J. Green neighborhoods, food retail and childhood overweight: differences by population density. *Am J Health Promot.* 2006; 21:317–325. [PubMed: 17465177]
- LWCFA - the Land and Water Conservation Fund Act. Public Law 88–578, Title 16, United States Code. 1965
- McConnell R, Islam T, Shankardass K, Jerrett M, Lurmann F, Gilliland F, et al. Childhood Incident Asthma and Traffic-Related Air Pollution at Home and School. *Environ Health Perspect.* 2010
- Mota J, Almeida M, Santos P, Ribiero JC. Perceived neighborhood environments and physical activity in adolescents. *Am J Prev Med.* 2005; 41:834–836.
- Navidi W, Thomas D, Stram D, Peters J. Design and analysis of multilevel analytic studies with applications to a study of air pollution. *Environ Health Perspect.* 1994; 102:25–32.
- Norman GJ, Nutter SK, Ryan S, Sallis JF, Calfas KJ, Patrick K. Community design and access to recreational facilities as correlates of adolescent physical activity and body-mass index. *J Phys Act Health.* 2006; 3:118–128.
- Ogden CL, Carroll MD, Flegal KM. High body mass index for age among US children and adolescents, 2003–2006. *JAMA.* 2008; 299:2401–2405. [PubMed: 18505949]
- Pate RR, Freedson PS, Sallis JF, Taylor WC, Sirard J, Trost SG, Dowda M. Compliance with physical activity guidelines: prevalence in a population of children and youth. *Ann Epidemiol.* 2002; 12:303–308. [PubMed: 12062916]
- Roenmich JN, Epstein LH, Raja S, Yin L, Robinson J, Winiewicz J. Association of access to parks and recreational facilities with the physical activity of young children. *Am J Prev Med.* 2006; 43:437–441.
- Sallis JF, Alcaraz JE, McKenzie TL, Hovell MF. Predictors of change in children's physical activity over 20 months: Variations by gender and level of adiposity. *Am J Prev Med.* 1999; 16:222–229. [PubMed: 10198662]
- Sallis JF, Hovell MF, Hofstetter CR. Predictors of adoption and maintenance of vigorous physical activity in men and women. *Am J Prev Med.* 1992; 21:237–251.
- Sallis JF, Johnson MF, Calfas KJ, Caparosa S, Nichols JF. Assessing perceived physical environmental variables that may influence physical activity. *Research Quarterly for Exercise and Sport.* 1997; 68:345–351. [PubMed: 9421846]
- Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. *Medicine and Science in Sports and Exercise.* 2000; 32:963–975. [PubMed: 10795788]
- Stunkard AJ. Genetic contributions to human obesity. *Res Publ Assoc Res Nerv Ment Dis.* 1991; 69:205–218. [PubMed: 2003161]
- Timperio A, Crawford D, Telford A. Perceptions about the local neighborhood and walking and cycling among children. *Am J Prev Med.* 2004; 38:39–47.
- UPARR - the Urban Park and Recreation Recovery Act. Public Law 95–625. The National Park Service of the Department of the Interior. 1978
- Wolch J, Wilson J, Fehrenbach J. Parks and park funding in Los Angeles: an equity mapping analysis. *Urban Geog.* 2005; 26:4–35.
- Yang TC, Wu PC, Chen VY, Su HJ. Cold surge: a sudden and spatially varying threat to health? *Sci Total Environ.* 2009; 407(10):3421–3424. [PubMed: 19162302]

Figure 1.
Distribution of park and recreational program resources.

Figure 2.
Recreational programs with 5 and 10 km buffers of children's homes.

Figure 3.
The study region with spatial distribution of parks.

Figure 4.
Access to recreational programs within 10km buffer.

Table 1

Specific Model Results per one unit change (point estimates).

Recreation Variables	Effect: Males (estimate/std)	Effect: Females (estimate/std)	Effect: Males + Females (estimate/std)
Park space (acres) within 500 m buffer ¹	-0.0126*** (0.0055)	-0.0070* (0.0048)	-0.0094*** (0.0037)
Recreation programs within 10 km buffer ²	-0.0228*** (0.005)	-0.0132*** (0.005)	-0.0176 ^{\$} *** (0.0048)

p-value < 0.05;

**
p-value < 0.1;

*
p-value < 0.2;

^{\$}
Gender Differences Testing with p-value < 0.05 (Based on LRT)

Table 2

Variables included in the multilevel growth curve analysis.

Variables	Data source ¹	Males + Females		Males		Females	
		N	Mean (std)	N	Mean (std)	N	Mean (std)
Traffic density within 150 m buffer of home	Annualized average daily traffic from the California	2943	26.729 (74.813)	1470	26.732 (75.369)	1473	26.726 (74.279)
Distance to nearest freeway	TeleAtlas	2943	3338.88 (4532.24)	1470	3417.36 (4657.58)	1473	3260.56 (4403.78)
Total arterial roadway length	TeleAtlas	3162	0.213 (0.6)	1572	0.212 (0.593)	1590	0.214 (0.608)
Population density	Census 1990	3162	1256.81 (1120.98)	1572	1247.05 (1048.4)	1590	1266.46 (1188.64)
Average urban imperviousness	NLCD	3162	31.005 (17.481)	1572	30.851 (17.27)	1590	31.158 (17.691)
Average tree canopy	NLCD	3162	5.707 (11.92)	1572	5.697 (11.852)	1590	5.717 (11.991)
Number of "X" Intersections	TeleAtlas	3162	9.48 (8.915)	1572	9.577 (8.931)	1590	9.384 (8.9)
Normalized difference vegetation index	Derived from Landsat Images	3162	0.059 (0.077)	1572	0.058 (0.076)	1590	0.059 (0.079)
Poverty in census block of home	Census 1990	3058	0.084 (0.093)	1518	0.083 (0.094)	1540	0.086 (0.091)
Forcible rape rate	California Dept. of Justice 1998	3318	37.106 (10.605)	1647	37.0417 (10.595)	1671	37.169 (10.618)

¹ Traffic volume data were collected for freeways, highways, arterials, and some major collectors by the California Department of Transportation Functional Class (FC) data for the year 2000. Traffic density was computed using a kernel estimate in the ArcGIS Spatial Analyst based on the line-link data with a 10 m grid cell size and a distance decay function of 90% within the first 150, 300, or 500 m (see Jerrett et al. 2010 for further details). Tree canopy data were acquired from the 2001 National Land Cover Database (NLCD), which provides new information about horizontal vegetation structure in the United States. NLCD is a nationwide map containing information about the percentage of tree canopy cover at a Landsat 30 m pixel resolution. NDVI - normalized difference vegetation index was derived from the 2001 Landsat Enhanced Thematic Mapper Plus (ETM+) data with a resolution of 30 m; higher NDVI means greater coverage of vegetation. Urban imperviousness was derived from NLCD tree canopy coverage data.

Table 3

Specific Model Results per one unit change (point estimates). In order to make comparable across risk factors, we estimated reduction in attained BMI based on 10–90% scale.

Variable of Interest	Effect: Males (estimate/std)	Effect: Females (estimate/std)	Effect: Males + Females (estimate/std)
Park space (acres) within 500 m buffer¹	−0.0126 ^{***} (0.0055)	−0.0070 [*] (0.0048)	−0.0094 ^{***} (0.0037)
Recreation programs within 10 km buffer²	−0.0228 ^{***} (0.005)	−0.0132 ^{***} (0.005)	−0.0176 ^{§***} (0.0048)

^{***} p-value < 0.05;

^{**} p-value < 0.1;

^{*} p-value < 0.2;

[§] Gender Differences Testing with p-value < 0.05 (Based on LRT)

[†] There were 142 cofounders tested for the model and the long list of cofounders made us decide not to show and define those cofounders not presented in the final model.

¹ Included Ethnicity, Town, Gender, Cohort variables, adjusted for AADT Density 150m, Average Urban Imperviousness within Buffer, Total Length of Arterial Roads within Buffer, Number of “X” Intersections within 500m, NDVI, and Percent below Poverty within Census Block.

² Included Ethnicity, Town, Gender, Cohort variables, adjusted for AADT Density 150m, Distance (m) from Residence to Nearest Freeway, Town Level Forcible Rape Rate, Buffer Population, Average Urban Imperviousness within Buffer, Average Tree Canopy within Buffer, Agriculture Land Use (KM²), Number of “X” Intersections within 500m, NDVI, and Percent below Poverty within Census Block.

Table 4

Effects on body mass index with increments in park space and recreation programs

Variable of Interest		BMI (kg m ⁻²)	95% CI	10–90% Range
Park space (acres) within 500 m buffer ¹	Male	−0.1863 (0.0815)	(−0.0267, −0.346)	14.82
	Female	−0.1034 (0.0708)	(0.0354, −0.2423)	
	Male + Female	−0.1389 (0.0544)	(−0.0322, −0.2456)	
Recreation programs (#) within 10 km buffer ²	Male	−1.8721 (0.4134)	(−1.0618, −2.6824)	82.00
	Female	−1.0802 (0.4081)	(−0.2803, −1.8801)	
	Male + Female	−1.4429 (0.3938)	(−0.6711, −2.2147)	

¹Included Ethnicity, Town, Gender, Cohort variables, adjusted for AADT Density 150m, Average Urban Imperviousness within Buffer, Total Length of Arterial Roads within Buffer, Number of “X” Intersections within 500m, NDVI, and Percent below Poverty within Census Block.

²Included Ethnicity, Town, Gender, Cohort variables, adjusted for AADT Density 150m, Distance (m) from Residence to Nearest Freeway, Town Level Forcible Rape Rate, Buffer Population, Average Urban Imperviousness within Buffer, Average Tree Canopy within Buffer, Agriculture Land Use (KM²), Number of “X” Intersections within 500m, NDVI, and Percent below Poverty within Census Block.