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Obesogenic Environments in Youth:

Concepts and Methods from a Longitudinal National Sample

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Abstract

To effectively prevent and reduce childhood obesity through healthy community design, it is essential to understand which neighborhood environment features influence weight gain in various age groups. However, most neighborhood environment research is cross-sectional, focuses on adults, and is often carried out in small, nongeneralizable geographic areas. Thus, there is a great need for longitudinal neighborhood environment research in diverse populations across the lifecycle. This paper describes: (1) insights and challenges of longitudinal neighborhood environment research and (2) advancements and remaining gaps in measurement and study design that examine individuals and neighborhoods within the context of the broader community. Literature-based research and findings from the "Obesity and Neighborhood Environment Database" (ONEdata), a unique longitudinal GIS that is spatially and temporally linked to data in the National Longitudinal Study of Adolescent Health (N=20,745), provide examples of current limitations in this area of research. Findings suggest a need for longitudinal methodologic advancements to better control for dynamic sources of bias, investigate and capture appropriate temporal frameworks, and address complex residential location processes within families. Development of improved neighborhood environment measures that capture relevant geographic areas within complex communities and investigation of differences across urbanicity and sociodemographic composition are needed. Further longitudinal research is needed to identify, refine, and evaluate national and local policies to most effectively reduce childhood obesity.

Introduction

Numerous local, state, and national obesity prevention initiatives target neighborhood diet and activity environments.[1–3] However, for these strategies to effectively reduce and prevent obesity, better understanding of which environment features influence weight gain throughout childhood and into adulthood is needed.[4–7] Such understanding necessitates longitudinal neighborhood-level obesity research,[8–10] which has only recently emerged in the literature.[11–17]

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The current paper describes: (1) insights and challenges of longitudinal neighborhood environment research and (2) advancements and remaining gaps in measures and study design that examine individuals and neighborhoods within the context of the broader community. Areas of focus are residential selection and mobility, measurement approaches, and subgroup-specific effects. Each issue is illustrated with examples from (1) the longitudinal "Obesity and Neighborhood Environment Database" (ONEdata), which contributes unique longitudinal GIS data tied to individual-level, nationally representative data spanning the adolescent to young adult years; (2) an analogous longitudinal cohort of adults, the Coronary Artery Risk in Young Adults study (CARDIA), as adults are key purchasers of food for children; and (3) key findings from the wider neighborhood environment literature, although there are few comparable studies.

Insights and Challenges of Longitudinal Neighborhood Environment Research

Cross-sectional neighborhood environment studies are particularly problematic because neighborhoods and individual behaviors evolve over time through complex, inter-related processes (Figure 1).[18] Individuals move in and out of neighborhoods according to financial or social constraints and residential preferences[19] (Figure 1, Pathways A,B). Individuals with physically active lifestyles and healthy diets may prefer and afford neighborhoods that support healthy behaviors[20–23] (Pathways C–E). Likewise, physical activity and food resources are placed in areas with the greatest demand, characterized in part by the characteristics of nearby residents (Pathways F,G).[24] The largely cross-sectional literature ignores these dynamic interactions and may grossly mis-estimate influences of neighborhood features on obesity-related behaviors.[25] With longitudinal data it is possible to address individual characteristics that may contribute to these temporal inter-relationships.[20]

To illustrate these limitations, findings are highlighted from Add Health, a nationally representative, prospective cohort study of adolescents representative of the U.S. school-based population in Grades 7 to 12 in 1994–1995 (Wave I) followed through 1995–1996 (Wave II, n=14,738) and into adulthood in 2001–2002 (Wave III, n=15,197) and 2007–2008 (Wave IV, n=15,701). As described elsewhere,[26] Add Health included a core sample plus subsamples of selected minority and other groupings collected under protocols approved by the IRB at the University of North Carolina at Chapel Hill. ONEdata includes >6000 time-varying built, economic, and social environment variables (Appendix A) from external sources linked to respondent residential locations at Waves I and III.[27] Environment measures capture areas within 1-, 3-, 5-, and 8-km straight-line (Euclidean neighborhood buffers) and street network (street network neighborhood buffer) distances around residences and within census block groups and tracts.[28] ONEdata captures 3.6% of 2000 census block groups (n=7558).

Longitudinal ONEdata findings suggest that reducing neighborhood crime and, for men/boys, providing for-pay physical activity facilities may promote physical activity as adolescents become young adults (Figure 2),[17] while limiting neighborhood fast-food availability may reduce fast-food consumption in low-income men (Figure 3).[29] Fewer neighborhood features were associated with obesity-related behaviors in girls/women, suggesting that promotion of healthy lifestyles in girls and women may be particularly difficult. Overall, findings suggest that improvements in landscape diversity, public physical activity facilities, and street connectivity may substantially increase physical activity (Figure 2),[17] and providing supermarkets and grocery stores may not result in improved diets (Figure 3).[29] These findings are consistent with other longitudinal studies showing inconsistent[15] or null associations between urban sprawl with walking or obesity,[11,12] and

mixed, generally null associations between food resources and obesity-related outcomes.[13,14,30]

These examples use fixed-effect longitudinal models, which condition on each individual, thereby analyzing variation observed within-person, over time, and adjusting for time-constant unmeasured characteristics;[9,33,34] in essence, each individual serves as his/her own control. Adjusting for these unmeasured characteristics is critical because they may be powerful drivers of location selection. Yet they are difficult to measure. For example, unmeasured outcome expectations of adults with school-aged children who are more likely to select a neighborhood with high-quality schools (and coincidentally more recreation resources) may influence adoption of physically active lifestyles and healthy diets (Figure 1, Pathway E).

Fixed-effects models control for such outcome expectations that remain constant between time points, although they do not address unmeasured characteristics that change over time (e.g., time constraints). Formal testing of longitudinal fixed-effects models compared to random-effects models (which do not control for time-constant unmeasured confounders and are thus more comparable to cross-sectional models) indicated that fixed effects were warranted (Hausman–Taylor test[31]) for a wide range of associations between neighborhood environments and diet[16] and physical activity[17,32] behaviors. Thus, unmeasured confounders were associated with the independent variables, and therefore random-effects estimates were biased.

Further, random-effects estimates were attenuated toward, to, or past the null.[17] This finding contrasts with the typical assumption that location-selection bias results in overestimation of neighborhood health effects due to selection of more-favorable environments by people with healthier lifestyles. Specifically, for-pay physical activity facilities (in boys/men) and crime (in girls/women) were more strongly related to physical activity in fixed-versus random-effects models.[17] Such facilities may be more common in commercial centers selected less often by more-advantaged, physically active families, which may explain why controlling for location-selection factors attenuates effects.

Neighborhood environment changes: residential relocation versus modifications around stationary residents

In the small body of longitudinal neighborhood environment research, most studies investigate health impacts of changes in neighborhood environments that result from relocation of individuals to new residential neighborhoods (residential mobility).[11,12,15,33] In contrast, policies assume that health will improve as a result of changes in neighborhoods around stationary residents. In an examination of both mechanisms, associations between physical activity facilities and physical activity behaviors were generally weaker or equivalent in those who did (versus did not) relocate to new residences.[17] However, this pattern could be reversed in adulthood, when residential stability is the norm.

Estimated impacts of neighborhood changes around stationary residents may reflect several processes. In the late teenage years, individuals may remain in their parental homes to care for their own young children, attend a local college, or for other reasons that may also affect physical activity levels. Likewise, neighborhoods change systematically, with disadvantaged groups experiencing more neighborhood economic decline.[19] Natural experiments before and after introductions of policies or facilities and other longitudinal studies of neighborhood change around stationary residents are clearly needed to disentangle systematic demographic and environmental changes from influences of specific neighborhood features on behavior.

Elucidation of behavioral pathways to improve understanding of neighborhood impacts on obesity

Studies that examine direct relationships between neighborhood environments and BMI (Figure 1, Pathway I) ignore behavioral pathways (Figure 1, Pathways D and H). Using complex modeling techniques to examine inter-related behavioral pathways,[34] greater availability of public physical activity facilities was related to lower BMI 6 years later but unrelated to concurrent physical activity and sedentary behaviors. Living farther from a neighborhood park was related to higher TV/video viewing and leisure computer use, but unrelated to BMI.[34] Sophisticated, longitudinal analysis with high-quality behavior data are needed to understand complex pathways underlying relationships between neighborhood environments, individuallevel behaviors, and health outcomes.

Three Key Challenges in Longitudinal Neighborhood Health Research (Table 1)

Controlling for complex, dynamic sources of bias

The findings above controlled for unmeasured characteristics that were constant over time. Addressing key unmeasured predictors of location selection that vary over time such as change in marital or employment status[35] requires better understanding of drivers of location selection. Simultaneous equation strategies[20] can explicitly model predictors of location selection in a first modeling stage, and instrumental variables[36] can also address time-varying unmeasured confounders. Natural experiments or randomized trials are critical for understanding causal effects of neighborhoods on health[25,37] but can be costly, pose ethical dilemmas, and often are not feasible for studying large-scale or combined impacts. Therefore, advances in observational research combined with experimental designs are needed.

Appropriate temporal framework

The above-described longitudinal models assume that effects of neighborhood features on physical activity and diet behaviors are relatively immediate (within the follow-up period). However, long-term and cumulative effects are possible. For example, neighborhood sports fields may promote youth sports participation, thereby developing skills and preferences for active lifestyles that carry through adolescence and into adulthood.[38] Likewise, improvement of diet in response to a new supermarket may occur over months or years as residents develop motivation and skill in preparing fresh produce. Innovative analytic approaches for capturing cumulative effects and investigating lag times between neighborhood modifications and changes in behavior and health are needed to understand such long-term impacts.

Residential selectivity in youth

Parents drive neighborhood selection and offspring behavior through modeling, supports, and rules,[39–41] which may influence later (adult) behavior.[42,43] Further, characteristics of previous residential locations are the most powerful predictors of subsequent residential neighborhood characteristics.[19,44] Therefore, biases related to residential selection in youth may mimic parental residential selection. Innovative strategies for addressing residential selectivity in youth require greater understanding of parental influences on residential choice and behavior.

Placing Individuals and Neighborhoods Within the Context of the Broader Community

Neighborhood development and population density may drive estimated influences of neighborhood resources and design

Common neighborhood resource availability measures such as raw counts of resources within a given area[45–49] or distance to the nearest resource[50–55] overlook the array of retail, industrial, educational, and residential facilities that cluster in predictable and inter-related ways. Indeed, pattern analysis of a large set of neighborhood environment variables[28] suggested that population density, intersection density, and counts of physical activity facilities represent underlying constructs of development intensity. Thus, intersection density (a common indicator of street connectivity[56–59]) and physical activity facility counts (a common measure of recreation opportunities) may be proxies for general development intensity.

Using density-scaled resource counts is one strategy to separate availability of physical activity and diet resources from development density. For example, scaling by population (resource counts per 10,000 population)[17,28] addresses the strong correlation between density of commercial establishments and population density and incorporates crowding as a facet of availability. Alternatively, roadway-scaled measures (resource counts per roadway mile)[3,60,61] represent the concentration of resources along access routes and may adjust for overall commercial activity. These density-scaled measures should be validated and further developed to better isolate the impacts of physical activity and food resources.

Relevant proximities vary across neighborhood features and across population subgroups

Accurate neighborhood measures must capture resources and design features within a relevant area, yet there is little theoretic or empirical guidance for delineating neighborhoods. Creating GIS boundaries and variables is therefore subjective,[62–65] although varying neighborhood definitions affect study findings in some studies[66] but not others.[58,67–69] In contrast to administrative units such as ZIP codes or U.S. census tracts, buffer-defined neighborhoods at specified Euclidean[68,70] or street network[57,71] distances around individual residential locations are specific to individual residents.

In comparative research across 1-, 3-, 5-, and 8.05-kilometer buffers, physical activity was most strongly related to greater intersection density within 1 km and to physical activity resources within 3 km of adolescents' homes. While street-based activity such as skateboarding or jogging may occur close to home,[43] families may be willing to travel longer distances to recreation facilities. Yet these associations vary by gender and income. For example, fast-food consumption was most strongly related to fast-food availability within 3km of homes in low-income men, who may be less likely to own a car, thereby limiting mobility and enhancing reliance on the immediate neighborhood area.[72]

In short, appropriate proximities may vary by the type of neighborhood feature and constraints of the target population. Empirical comparisons of varying neighborhood definitions and movement toward standard, objective definitions will facilitate greater measurement accuracy and comparability across studies.[73] Studies incorporating diverse geographic scales will also inform multilevel policies aimed at local neighborhoods as well as counties and states.

Physical activity and food environments may operate differently in rural, suburban, and urban areas

Much neighborhood environment research has been in major metropolitan areas, yet research within a geographically diverse population suggests variation in results across the urban spectrum.[60,74,75] In contrast with the typical dichotomous classification of rural versus urban based on population density, the multidimensional concept of urbanicity and rurality may be better captured by classifying according to U.S. Census–defined "urbanized areas," augmented with percentage of developed land cover to provide nuanced approximations of non-urban (rural), low-density urban (suburban), and high-density urban (central urban) areas.[74,76]

Using this strategy, greater physical activity was associated with higher intersection density and in non-urban and high-density urban areas,[74] but with physical activity facilities only in low-density urban areas.[74] There is likely great variation in neighborhood environment and behaviors across these different settings. For example, walkability might have less relevance in rural areas, where walking to destinations is rare, as well as in urban centers where retail destinations are ubiquitous but personal safety concerns interfere with access. Similarly, individual and household characteristics that drive selection of homes in rural, suburban, and urban areas are poorly understood but may underlie differences in association between environment and obesity-related behaviors.

Disparities in neighborhood environments are not straightforward

Neighborhood environment research and policies often assume less access to physical activity and healthy food resources in poor neighborhoods, but evidence is inconsistent.[3,10,77] For example, neighborhoods with both higher income and education had more intermixed land use, development density, and physical activity resources.[28,78] However, "reverse" disparities have been observed in relation to the social environment: areas with high crime and high racial minority populations had greater intermixed land use, development density and resources,[28] and lower availability of convenience stores, which typically provide energy-dense, nutrient-poor foods.[75] In addition, racial and income disparities in availability of grocery/supermarkets were more apparent in low-density urban (suburban) areas than in high-density urban areas.[79–84] Access to healthy neighborhood resources appears to be driven by complex economic and social influences that may vary across geographic contexts.

Future Directions in Understanding Specific Neighborhood Impacts Within Complex Communities

Improved characterization of neighborhood environments requires investigation of the following knowledge gaps (Table 1):

1. Salient neighborhood area(s): First, any neighborhood intervention may exert differing effects at the micro and macro scales.[85] For example, state transportation policies can promote bike infrastructure development, which in turn may encourage cycling if adopted throughout communities, but may have little impact if confined to specific neighborhoods within communities. Second, resources may benefit residents in adjoining neighborhoods,[86] yet the importance and size of such spatial lag is largely unexplored. Third, only a handful of studies examine environments outside the residential neighborhood, yet much activity and food consumption takes place at, or around, work and school. Appropriate development and targeting of neighborhood interventions require advancements in understanding and measuring

meaningful neighborhoods and proximities using a wide variety of empirical and theoretic approaches.[87]

2. Variation in effects across urbanicity: Understanding which resources and design features are relevant to youth in different geographic contexts requires disentangling the critical socioeconomic, political, and infrastructural factors represented by urbanicity.[88] Comparative research across rural,[89,90] suburban, and urban neighborhoods is needed. This is critical because findings from studies conducted in major metropolitan areas may not be generalizable, and neighborhood interventions likely need tailoring to local needs.

3. Critical leverage points: Creation of effective policies requires greater understanding of the temporal sequencing of processes that generate neighborhood disparities. For example, resolution of disparities resulting from differential demand for certain products or services might require parallel interventions addressing social and economic barriers and physical access. Resolution of disparities that result from gentrification[91] in which healthy resources attract high-income households might require provision of physical access coupled with affordable housing policies[92] to retain low-income families.

4. Enhancing existing or improved built environments: Understanding how built environment infrastructure interacts with community processes can provide insights about why some environment features relate to behaviors and health in some areas but not others, and can identify community programs with potential to overcome barriers. For example, lack of walkability could be overcome by an active youth center, and recreation programs can enhance the impacts of park renovations.[93]

Gaps in Translation of Research to Policy

The literature also suggests needs related to creating policies that effectively promote healthy lifestyles and reduce obesity in youth (Table 1).

1. Addressing barriers within specific subgroups: For example, findings that for-pay physical activity facilities relate to lower physical activity in girls/women may reflect a need to tailor facilities and programs to meet the needs of adolescent girls.[94] Similarly, for supermarkets to successfully improve diets, promoting new or existing resources within target groups may be necessary.[95]

2. Promising policy strategies: Improving neighborhood resources should be weighed against alternative approaches such as taxation, subsidization, or incentives (e.g., reduced-cost exercise programs, sugar-sweetened beverage tax[96]). Direct comparison of various policy strategies using common health metrics may facilitate evidence-based policy making.[97,98]

Limitations

While limitations have been discussed here across the field of neighborhood research, longitudinal data have been used to provide many illustrative examples, largely due to the lack of comparable longitudinal data. These data may have error, a well recognized limitation in neighborhood environment research.[99–105] In addition, while Add Health offers the advantages of a large, nationally representative study population, these data do not capture unique aspects of small localities throughout the U.S. Combined knowledge from large national studies with studies in focused geographic areas and subpopulations is needed to understand how neighborhoods influence obesity across diverse populations.

Conclusion

Investigation and resolution of methodologic issues raised by the small but growing body of longitudinal neighborhood research will become critical as future longitudinal research is developed and more longitudinal data become available. Advancements in characterization of neighborhood environments that capture relevant geographic areas and scales of influence, differences across urbanicity and neighborhood sociodemographics, and diverse physical and social resources are needed. Finally, further research is needed to test the robustness of existing evidence and refine policies to target neighborhood resources with the greatest benefit to population health.

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The more extensive restricted-use data, available by contractual agreement, are distributed only to certified researchers who have an IRB-approved security plan for handling and storing sensitive data and sign a data-use contract agreeing to protect data confidentiality.

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References

1. Let's Move. Eat Healthy - Healthy Communities. 2011. www.letsmove.gov/healthy-communities
2. New York Economic Development Corp. New York City industrial development agency approves incentives for first two supermarkets under the fresh program. 2010. www.nycedc.com/PressRoom/PressReleases/Pages/IDAApprovesIncentivesforSupermarkets.aspx
3. Sturm R, Cohen DA. Zoning for health? the year-old ban on new fast-food restaurants in south LA. Health Aff (Millwood). 2009 Oct 6.
4. Gordon-Larsen P, Adair LS, Nelson MC, Popkin BM. Five-Year obesity incidence in the transition period between adolescence and adulthood: the National Longitudinal Study of Adolescent Health. Am J Clin Nutr. 2004; 80:569–575. [PubMed: 15321794]
5. Telama R, Yang X, Viikari J, Valimaki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. Am J Prev Med. 2005; 28(3):267–273. [PubMed: 15766614]
6. Tammelin T, Laitinen J, Nayha S. Change in the level of physical activity from adolescence into adulthood and obesity at the age of 31 years. Int J Obes Relat Metab Disord. 2004 Jun; 28(6):775–782. [PubMed: 15037883]
7. Kvaavik E, Tell GS, Klepp KI. Predictors and tracking of body mass index from adolescence into adulthood: follow-up of 18 to 20 years in the Oslo Youth Study. Arch Pediatr Adolesc Med. 2003 Dec; 157(12):1212–1218. [PubMed: 14662578]

8. Saelens BE, Handy SL. Built environment correlates of walking: a review. Med Sci Sports Exerc. 2008; 40(7 Suppl):S550–S566. [PubMed: 18562973]
9. Wendel-Vos W, Droomers M, Kremers S, Brug J, van Lenthe F. Potential environmental determinants of physical activity in adults: a systematic review. Obes Rev. 2007 Sep; 8(5):425–440. [PubMed: 17716300]
10. Larson NI, Story MT, Nelson MC. Neighborhood environments: disparities in access to healthy foods in the U.S. Am J Prev Med. 2009 Jan; 36(1):74–81. [PubMed: 18977112]
11. Lee IM, Ewing R, Sesso HD. The built environment and physical activity levels: the Harvard Alumni Health Study. Am J Prev Med. 2009 Oct; 37(4):293–298. [PubMed: 19765500]
12. Eid J, Overman HG, Puga D, Turner MA. Fat city: Questioning the relationship between urban sprawl and obesity. J Urban Economics. 2008; 63(2):385–404.
13. Block JP, Christakis NA, O'Malley AJ, Subramanian SV. Proximity to food establishments and body mass index in the framingham heart study offspring cohort over 30 years. Am J Epidemiol. 2011 Sep 30.
14. Gibson DM. The neighborhood food environment and adult weight status: estimates from longitudinal data. Am J Public Health. 2011 Jan; 101(1):71–78. [PubMed: 21088263]
15. Coogan PF, White LF, Adler TJ, Hathaway KM, Palmer JR, Rosenberg L. Prospective study of urban form and physical activity in the Black Women's Health Study. Am J Epidemiol. 2009 Nov 1; 170(9):1105–1117. [PubMed: 19808635]
16. Boone-Heinonen J, Gordon-Larsen P, Kiefe CI, Shikany JM, Lewis CE, Popkin BM. Fast food restaurants and food stores: longitudinal associations with diet in young to middle-aged adults: The CARDIA Study. Arch Intern Med. 2011; 171(13):1162–1170. [PubMed: 21747011]
17. Boone-Heinonen J, Guilkey DK, Evenson KR, Gordon-Larsen P. Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood. Int J Behav Nutr Phys Act. 2010; 7:70. [PubMed: 20920341]
18. Plantinga AJ, Bernell S. A spatial economic analysis of urban land use and obesity. Journal of Regional Science. 2005; 45(3):473–492.
19. Sampson RJ, Sharkey P. Neighborhood selection and the social reproduction of concentrated racial inequality. Demography. 2008 Feb; 45(1):1–29. [PubMed: 18390289]
20. Boone-Heinonen J, Gordon-Larsen P, Guilkey D, Jacobs DR, Popkin BM. Environment and physical activity dynamics: the role of residential self-selection. Psych Sport Exercise. 2011; 12:54–60.
21. Auchincloss AH, Riolo RL, Brown DG, Cook J, Diez Roux AV. An agent-based model of income inequalities in diet in the context of residential segregation. Am J Prev Med. 2011 Mar; 40(3):303–311. [PubMed: 21335261]
22. Bhat CR, Guo JY. A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. Transportation Research Part B-Methodological. 2007; 41(5):506–526.
23. Mokhtarian PL, Cao X. Examining the impacts of residential selection on travel behavior: a focus on methodologies. Trans Research Part B. 2008; 42:204–228.
24. Samadi N. IBISWorld Industry Report 72221: Fast food restaurants in the U.S. 2010
25. Oakes JM. The (mis)estimation of neighborhood effects: causal inference for a practicable social epidemiology. Soc Sci Med. 2004 May; 58(10):1929–1952. [PubMed: 15020009]
26. Resnick MD, Bearman PS, Blum RW, et al. Protecting adolescents from harm. Findings from the National Longitudinal Study on Adolescent Health. JAMA. 1997 Sep 10.278:823–832. [PubMed: 9293990]
27. Carolina Population Center. ONEdata - Obesity & Neighborhood Environment Database. www.cpc.unc.edu/projects/onedata
28. Boone-Heinonen J, Evenson KR, Song Y, Gordon-Larsen P. Built and socioeconomic environments: patterning and associations with physical activity in U.S. adolescents. Int J Behav Nutr Phys Act. 2010; 7:45. [PubMed: 20487564]
29. Boone-Heinonen J, Gordon-Larsen P, Kiefe CI, Lewis CE, Shikany J, Popkin BM. Fast food restaurants and food stores: longitudinal associations with diet in young adults: The CARDIA Study. Arch Intern Med. (in press).

30. Leung CW, Laraia BA, Kelly M, et al. The influence of neighborhood food stores on change in young girls' body mass index. Am J Prev Med. 2011 Jul; 41(1):43–51. [PubMed: 21665062]
31. Davidson, R.; MacKinnon, JG. Estimation and inference in econometrics. New York: Oxford University Press; 1993.
32. Boone-Heinonen J, Diez Roux AV, Kiefe CI, Lewis CE, Guilkey DK, Gordon-Larsen P. Neighborhood socioeconomic status predictors of physical activity through young to middle adulthood: The CARDIA study. Soc Sci Med. 2011 Mar; 72(5):641–649. [PubMed: 21316829]
33. Krizek KJ. Residential relocation and changes in urban travel. J Am Plan Assn. 2003 Summer; 69(3):265–281. 2003.
34. Boone-Heinonen J, Gordon-Larsen P. How might the built environment influence obesity? The contribution of physical activity and sedentary behavior. Obesity (Silver Spring). 2010; 18(Supp2):S129.
35. Geist C, McManus PA. Geographical mobility over the life course: Motivations and implications. Population Space and Place. 2008; 14(4):283–303.
36. Hernan MA, Robins JM. Instruments for causal inference: an epidemiologist's dream? Epidemiology. 2006; 17(4):360–372. [PubMed: 16755261]
37. Glymour, MM. Natural experiments and instrumental variable analysis in social epidemiology. In: Oakes, JM.; Kaufman, JS., editors. Methods in Social Epidemiology. San Francisco: Jossey-Bass; 2006.
38. Glymour MM. Sensitive periods and first difference models: integrating etiologic thinking into econometric techniques: a commentary on Clarkwest's "Neo-materialist theory and the temporal relationship between income inequality and longevity change". Soc Sci Med. 2008 May; 66(9): 1895–1902. discussion 1903-1898. [PubMed: 18281135]
39. Hingle MD, O'Connor TM, Dave JM, Baranowski T. Parental involvement in interventions to improve child dietary intake: a systematic review. Prev Med. 2010; 51(2):103–111. [PubMed: 20462509]
40. Barradas DT, Fulton JE, Blanck HM, Huhman M. Parental influences on youth television viewing. J Pediatr. 2007; 151(4):369–373. 373 e361 364. [PubMed: 17889071]
41. O'Connor TM, Jago R, Baranowski T. Engaging parents to increase youth physical activity a systematic review. Am J Prev Med. 2009; 37(2):141–149. [PubMed: 19589450]
42. Gordon-Larsen P, Nelson MC, Popkin BM. Longitudinal physical activity and sedentary behavior trends: adolescence to adulthood. Am J Prev Med. 2004 Nov; 27(4):277–283. [PubMed: 15488356]
43. Nelson MC, Gordon-Larsen P, Adair LS, Popkin BM. Adolescent physical activity and sedentary behavior: patterning and long-term maintenance. Am J Prev Med. 2005; 28(3):259–266. [PubMed: 15766613]
44. Clark WAV, Ledwith V. How much does income matter in neighborhood choice? Population Res Policy Rev. 2007; 26(2):145–161.
45. Lee RE, Cubbin C, Winkleby M. Contribution of neighbourhood socioeconomic status and physical activity resources to physical activity among women. J Epidemiol Community Health. 2007 Oct; 61(10):882–890. [PubMed: 17873224]
46. Lopez RP. Neighborhood risk factors for obesity. Obesity (Silver Spring). 2007 Aug; 15(8):2111–2119. [PubMed: 17712130]
47. Paquet C, Daniel M, Knauper B, Gauvin L, Kestens Y, Dube L. Interactive effects of reward sensitivity and residential fast-food restaurant exposure on fast-food consumption. Am J Clin Nutr. 2010 Mar; 91(3):771–776. [PubMed: 20089726]
48. Pate RR, Colabianchi N, Porter D, Almeida MJ, Lobelo F, Dowda M. Physical activity and neighborhood resources in high school girls. Am J Prev Med. 2008; 34(5):413–419. [PubMed: 18407008]
49. Gary-Webb TL, Baptiste-Roberts K, Pham L, et al. Neighborhood and weight-related health behaviors in the Look AHEAD (Action for Health in Diabetes) study. BMC Public Health. Jun 4.10(1):312. [PubMed: 20525373]

50. Bodor JN, Rose D, Farley TA, Swalm C, Scott SK. Neighbourhood fruit and vegetable availability and consumption: the role of small food stores in an urban environment. Public Health Nutr. 2008; 11(4):413–420. [PubMed: 17617930]
51. Jago R, Baranowski T, Baranowski JC, Cullen KW, Thompson D. Distance to food stores & adolescent male fruit and vegetable consumption: mediation effects. Int J Behav Nutr Phys Act. 2007; 4:35. [PubMed: 17850673]
52. Laraia BA, Siega-Riz AM, Kaufman JS, Jones SJ. Proximity of supermarkets is positively associated with diet quality index for pregnancy. Prev Med. 2004 Nov; 39(5):869–875. [PubMed: 15475018]
53. Pearson T, Russell J, Campbell MJ, Barker ME. Do 'food deserts' influence fruit and vegetable consumption?--A cross-sectional study. Appetite. 2005 Oct; 45(2):195–197. [PubMed: 15927303]
54. Thornton LE, Bentley RJ, Kavanagh AM. Fast food purchasing and access to fast food restaurants: a multilevel analysis of VicLANES. Int J Behav Nutr Phys Act. 2009; 6:28. [PubMed: 19473503]
55. Zenk SN, Lachance LL, Schulz AJ, Mentz G, Kannan S, Ridella W. Neighborhood retail food environment and fruit and vegetable intake in a multiethnic urban population. Am J Health Promot. 2009; 23(4):255–264. [PubMed: 19288847]
56. Ball K, Timperio A, Salmon J, Giles-Corti B, Roberts R, Crawford D. Personal, social and environmental determinants of educational inequalities in walking: a multilevel study. J Epidemiol Commun Health. 2007; 61(2):108–114.
57. Frank LD, Schmid TL, Sallis JF, Chapman J, Saelens BE. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am J Prev Med. 2005 Feb; 28(2 Suppl 2):117–125. [PubMed: 15694519]
58. Forsyth A, Hearst M, Oakes JM, Schmitz KH. Design and destinations: Factors influencing walking and total physical activity. Urban Studies. 2008 Aug; 45(9):1973–1996.
59. Rundle A, Roux AV, Free LM, Miller D, Neckerman KM, Weiss CC. The urban built environment and obesity in New York City: a multilevel analysis. Am J Health Promot. 2007; 21(4 Suppl):326–334. [PubMed: 17465178]
60. Richardson AS, Boone-Heinonen J, Gordon-Larsen P. Neighborhood fast food restaurants and fast food consumption: a national study. (under review).
61. Romley JA, Cohen D, Ringel J, Sturm R. Alcohol and environmental justice: the density of liquor stores and bars in urban neighborhoods in the U.S. J Stud Alcohol Drugs. 2007; 68(1):48–55. [PubMed: 17149517]
62. Diez Roux AV. Investigating neighborhood and area effects on health. Am J Public Health. 2001; 91(11):1783–1789. [PubMed: 11684601]
63. Sampson RJ, Morenoff JD, Gannon-Rowley T. Assessing "Neighborhood Effects": Social processes and new directions for research. Ann Rev Sociol. 2002; 28:443–478.
64. Soobader M, Cubbin C, Gee GC, Rosenbaum A, Laurenson J. Levels of analysis for the study of environmental health disparities. Environ Res. 2006; 102(2):172–180. [PubMed: 16781704]
65. Stafford M, Duke-Williams O, Shelton N. Small area inequalities in health: Are we underestimating them? Soc Sci Med. 2008; 67(6):891–899. [PubMed: 18599174]
66. Zhang, M.; Kukadia, N. Transportation and Land Development 2005. Washington: Transportation Research Board Natl Research Council; 2005. Metrics of urban form and the modifiable areal unit problem; p. 71-79.
67. Berke EM, Koepsell TD, Moudon AV, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. Am J Public Health. 2007 Mar; 97(3):486–492. [PubMed: 17267713]
68. Diez Roux AV, Evenson KR, McGinn AP, et al. Availability of recreational resources and physical activity in adults. Am J Public Health. 2007; 97(3):493–499. [PubMed: 17267710]
69. Lovasi GS, Moudon AV, Smith NL, et al. Evaluating options for measurement of neighborhood socioeconomic context: evidence from a myocardial infarction case-control study. Health Place. 2008 Sep; 14(3):453–467. [PubMed: 17950024]
70. Cohen DA, Marsh T, Williamson S, et al. Parks and physical activity: why are some parks used more than others? Prev Med. 2010 Jan; 50(Suppl 1):S9–S12. [PubMed: 19850067]

71. King WC, Belle SH, Brach JS, Simkin-Silverman LR, Soska T, Kriska AM. Objective measures of neighborhood environment and physical activity in older women. Am J Prev Med. 2005; 28(5): 461–469. [PubMed: 15894150]
72. Inagami S, Cohen DA, Brown AF, Asch SM. Body mass index, neighborhood fast food and restaurant concentration, and car ownership. J Urban Health. 2009; 86(5):683–695. [PubMed: 19533365]
73. Chaix B. Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research agenda. Annu Rev Public Health. 2009; 30:81–105. [PubMed: 19705556]
74. Boone-Heinonen J, Popkin BM, Song Y, Gordon-Larsen P. What neighborhood area captures built environment features related to adolescent physical activity? Health Place. 2010 Nov; 16(6):1280–1286. [PubMed: 20650673]
75. Richardson AS, Boone-Heinonen J, Popkin BM, Gordon-Larsen P. Are neighborhood food resources distributed inequitably by income and race? Findings across the urban spectrum. (under review).
76. Richardson AS, Boone-Heinonen J, Popkin BM, Gordon-Larsen P. Neighborhood fast food restaurants and fast food consumption: a national study. BMC Public Health. 2011; 11:543. [PubMed: 21740571]
77. Macintyre S. Deprivation amplification revisited; or, is it always true that poorer places have poorer access to resources for healthy diets and physical activity? Int J Behav Nutr Phys Act. 2007; 4:32. [PubMed: 17683624]
78. 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 Febrary;117(2):417–424. 2006. [PubMed: 16452361]
79. Block JP, Scribner RA, DeSalvo KB. Fast food, race/ethnicity, and income: a geographic analysis. Am J Prev Med. 2004 Oct; 27(3):211–217. [PubMed: 15450633]
80. Morland K, Filomena S. Disparities in the availability of fruits and vegetables between racially segregated urban neighbourhoods. Public Health Nutr. 2007 Dec; 10(12):1481–1489. [PubMed: 17582241]
81. Morland K, Wing S, Diez Roux A, Poole C. Neighborhood characteristics associated with the location of food stores and food service places. Am J Prev Med. 2002 Jan; 22(1):23–29. [PubMed: 11777675]
82. Wang MC, Kim S, Gonzalez AA, MacLeod KE, Winkleby MA. Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. J Epidemiol Community Health. 2007 Jun; 61(6):491–498. [PubMed: 17496257]
83. Zenk SN, Powell LM. U.S. secondary schools and food outlets. Health Place. 2008 Jun; 14(2):336–346. [PubMed: 17881277]
84. Zenk SN, Schulz AJ, Israel BA, James SA, Bao S, Wilson ML. Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitan Detroit. Am J Public Health. 2005; 95(4):660–667. [PubMed: 15798127]
85. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exerc Sport Sci Rev. 2005 Oct; 33(4):175–181. [PubMed: 16239834]
86. Auchincloss AH, Diez Roux AV, Brown DG, O'Meara ES, Raghunathan TE. Association of insulin resistance with distance to wealthy areas: the multi-ethnic study of atherosclerosis. Am J Epidemiol. 2007 Feb 15; 165(4):389–397. [PubMed: 17148499]
87. Cummins S, Curtis S, Diez-Roux AV, Macintyre S. Understanding and representing 'place' in health research: a relational approach. Soc Sci Med. 2007 Nov; 65(9):1825–1838. [PubMed: 17706331]
88. Vlahov D, Galea S. Urbanization, urbanicity, and health. J Urban Health-Bulletin of the New York Academy of Medicine. 2002 Dec; 79(4):S1–S12.
89. Sharkey JR, Johnson CM, Dean WR. Food access and perceptions of the community and household food environment as correlates of fruit and vegetable intake among rural seniors. BMC Geriatr. 2010; 10:32. [PubMed: 20525208]

90. Sharkey JR, Horel S, Dean WR. Neighborhood deprivation, vehicle ownership, and potential spatial access to a variety of fruits and vegetables in a large rural area in Texas. Int J Health Geogr. 2010; 9:26. [PubMed: 20500853]
91. Fan Y. Reexamining contemporary urbanism in the United States: convenient mix of the old and new. Environment and Planning A. 2010; 42:2897–2913.
92. Katz, B.; Turner, M.; Brown, K.; Cunningham, M.; Sawyer, N. Rethinking local affordable housing strategies: lessons from 70 years of policy and practice. The Brookings Institution and The Urban Institute Discussion Paper: www.brookings.edu/reports/2003/12metropolitanpolicy_katz.aspx. 2003.
93. Cohen DA, Sehgal A, Williamson S, Marsh T, Golinelli D, McKenzie TL. New recreational facilities for the young and the old in Los Angeles: policy and programming implications. J Public Health Policy. 2009; 30(Suppl 1):S248–S263. [PubMed: 19190577]
94. Camacho-Minano MJ, Lavoi NM, Barr-Anderson DJ. Interventions to promote physical activity among young and adolescent girls: a systematic review. Health Educ Res. 2011 Jun 16.
95. Cummins S, Petticrew M, Higgins C, Findlay A, Sparks L. Large scale food retailing as an intervention for diet and health: quasi-experimental evaluation of a natural experiment. J Epidemiol Community Health. 2005 Dec; 59(12):1035–1040. [PubMed: 16286490]
96. Duffey KJ, Gordon-Larsen P, Shikany JM, Guilkey D, Jacobs DR Jr, Popkin BM. Food price and diet and health outcomes: 20 years of the CARDIA Study. Arch Intern Med. 2010 Mar 8; 170(5): 420–426. [PubMed: 20212177]
97. Carter R, Moodie M, Markwick A, et al. Assessing cost-effectiveness in obesity (ACE-obesity): an overview of the ACE approach, economic methods and cost results. BMC Public Health. 2009; 9:419. [PubMed: 19922625]
98. Insall P. Can we achieve evidence-based policy and practice on active travel? J Public Health Policy. 2009; 30(Suppl 1):S21–S25. [PubMed: 19190575]
99. Matthews SA, Moudon AV, Daniel M. Work group II: Using Geographic Information Systems for enhancing research relevant to policy on diet, physical activity, and weight. Am J Prev Med. 2009 Apr; 36(4 Suppl):S171–S176. [PubMed: 19285210]
100. Boone JE, Gordon-Larsen P, Stewart JD, Popkin BM. Validation of a GIS facilities database: quantification and implications of error. Ann Epidemiol. 2008 May; 18(5):371–377. [PubMed: 18261922]
101. Paquet C, Daniel M, Kestens Y, Leger K, Gauvin L. Field validation of listings of food stores and commercial physical activity establishments from secondary data. Int J Behav Nutr Phys Act. 2008; 5:58. [PubMed: 19000319]
102. Cummins S, Macintyre S. Are secondary data sources on the neighbourhood food environment accurate? Case-study in Glasgow, U.K. Prev Med. 2009 Dec; 49(6):527–528. [PubMed: 19850072]
103. Hoehner CM, Schootman M. Concordance of commercial data sources for neighborhood-effects studies. J Urban Health. 2010 Jul; 87(4):713–725. [PubMed: 20480397]
104. Liese AD, Colabianchi N, Lamichhane AP, et al. Validation of 3 food outlet databases: completeness and geospatial accuracy in rural and urban food environments. Am J Epidemiol. 2010 Dec 1; 172(11):1324–1333. [PubMed: 20961970]
105. Longacre MR, Primack BA, Owens PM, et al. Public directory data sources do not accurately characterize the food environment in two predominantly rural States. J Am Diet Assoc. 2011 Apr; 111(4):577–582. [PubMed: 21443992]

Appendix A. Key ONEdataa neighborhood environment measures

Measure	Variable description	Data source
Street connectivity	Alpha index: ratio of observed to maximum possible route alternatives between nodes (intersections); high values indicate high connectivity.	ESRI StreetMap

Measure	Variable description	Data source
Intersection density	Number of three- or more-way intersections (≥links in a single node) per square kilometer	ESRI StreetMap
Physical activity facilities	Categorized based on exploratory factor analysis findings	Dun & Bradstreet
For-pay	Instruction, member, public fee facilities	
Free public	Public, youth organizations	
Food resources		Dun & Bradstreet
Grocery stores	Independent and chain grocery stores and supermarkets (supermarkets and grocery stores are separate in some analyses)	
Convenience stores	Variety and convenience stores and food stores attached to gasoline filling stations	
Fast-food restaurants	Fast-food chain and nonchain restaurants, excluding food stands and cafeterias (fast-food chains are isolated in some analyses)	
Parks	Neighborhood parks Major park	ESRI StreetMap Pro, parks component
Greenspace	Area of recreational or undeveloped land as proportion of total land cover excluding water and ice	National land cover data set
Landscape diversity	Simpson's diversity index: Represents the probability that any two pixels selected at random would be different patch types.	National land cover data set
Population density	Count of persons per square mile	U.S. Census
Below poverty, %	People living in households with income below the federal poverty level (or below 150% of federal poverty level)	U.S. Census
Minority, %	People with race/ethnicity other than white non-Hispanic	U.S. Census
Median household income	Median household income	U.S. Census
Crime rate	Number of nonviolent and violent crimes per 100,000 population	Uniform Crime Reporting data

[a]ONEdata: Obesity and Neighborhood Environment Database; presented variables are key variables from published research, comprising a subset of >6,000 variables contained in ONEdata.

ESRI,

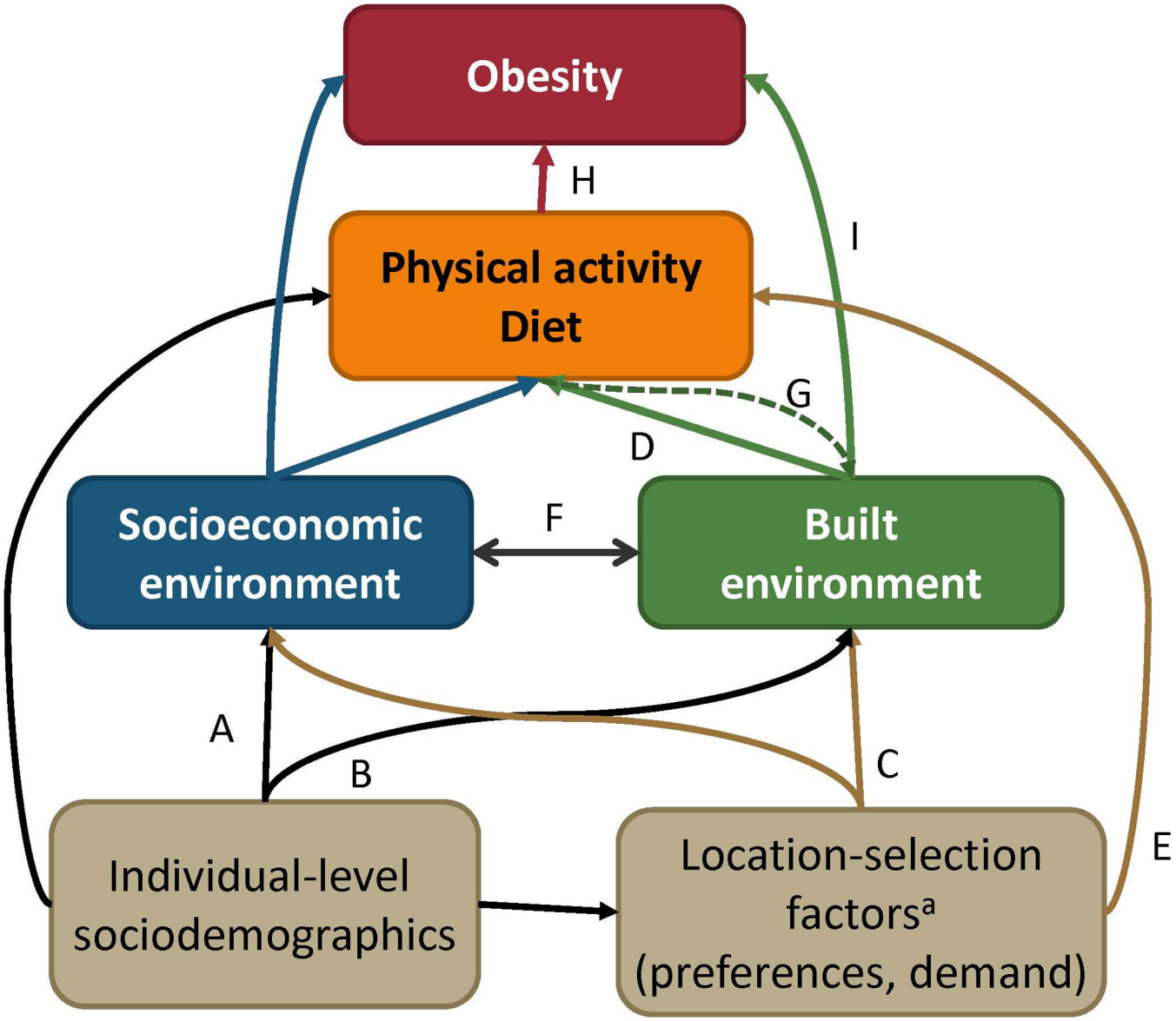

Figure 1.
Conceptual model of relationships among neighborhood environment features and individual-level characteristics, behaviors, and obesity
[a] Location-selection factors may be difficult or impossible to measure.

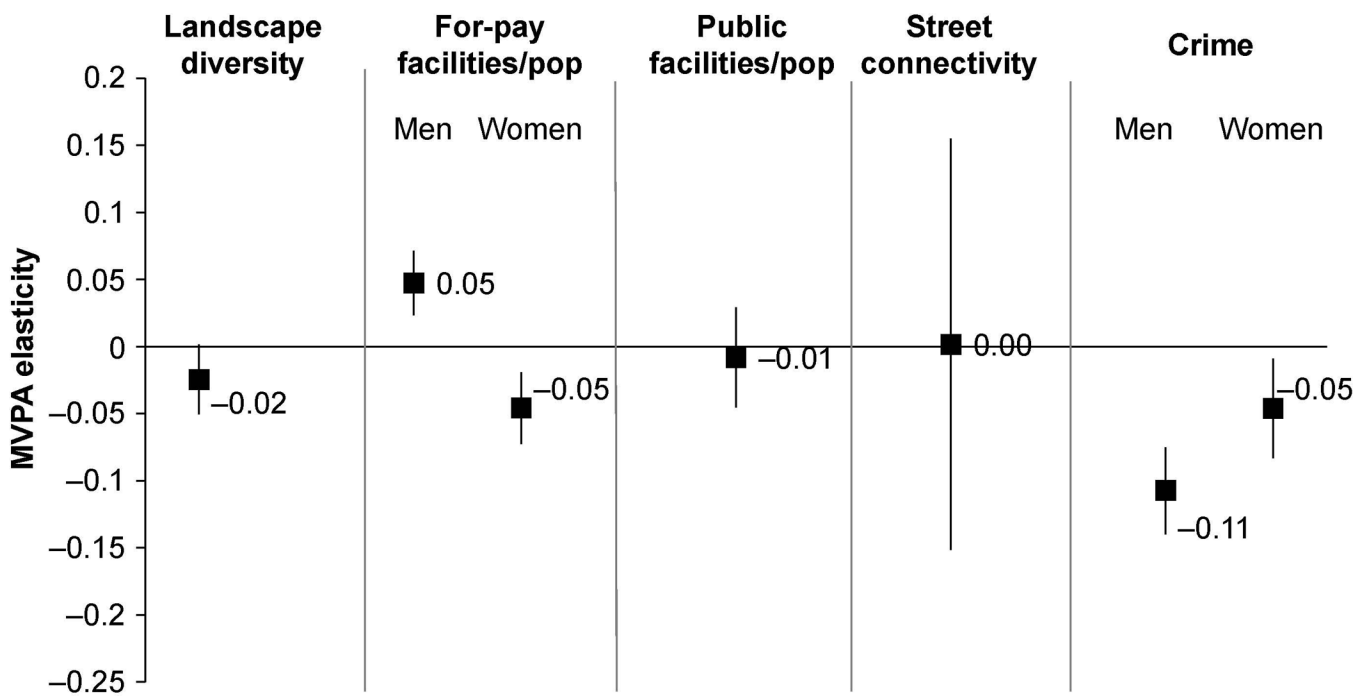

Figure 2.

Promising candidates for physical activity environment policy

Note: Figure shows longitudinal effect estimates of neighborhood environment characteristics on physical activity between adolescence (Wave I, 1994–1995) and young adulthood (Wave III, 2001–2002). Data are from the National Longitudinal Study of Adolescent Health (U.S.; n=12,701); estimated from Poisson fixed-effects regression modeling MVPA as a function of six natural log-transformed built and socioeconomic environment measures. Fixed-effects models are adjusted for time-varying age and do not estimate parameters for time-invariant individual-level variables. Estimates can be interpreted as the percentage change in MVPA expected from a 1% change in neighborhood characteristic. Error bars represent 95% CIs.

MVPA, moderate-to-vigorous physical activity (bouts per week); pop, population

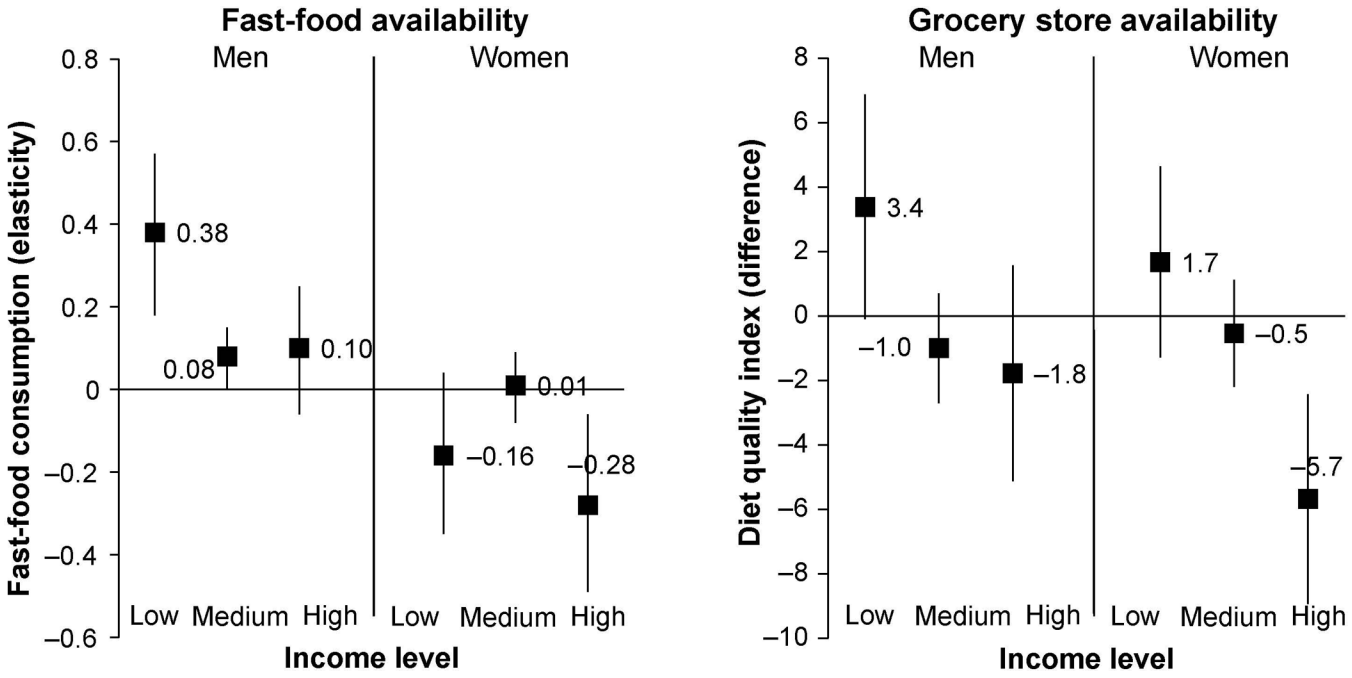

Figure 3.

Promising candidates for food environment policy

Note: Figure shows longitudinal effect estimates of fast-food availability on weekly frequency of fast-food consumption[a] and grocery store availability on diet quality,[b] by individual-level income. The estimates are from the Coronary Artery Risk Development in Young Adults (CARDIA) Study (1985–2000). They are adjusted for time-varying age, income, marital status, children in household and percentage of people below 150% of the federal poverty level; race, education, and study center are time-invariant and therefore omitted from fixed-effects models. Income-specific estimates were obtained from models containing income interactions with fast-food restaurant or grocery store availability within each neighborhood area. Error bars represent 95% CIs.

[a] Estimated using fixed-effects Poisson regression modeling fast-food consumption (times per week) as a function of fast-food restaurant availability (fast-food restaurant counts per 10,000 population) in the areas within 3 km of each respondent's home; coefficients can be interpreted as the percentage change in consumption expected from a 1% change in restaurant availability.

[b] Estimated using fixed-effects linear regression modeling diet quality index as a function of grocery store availability (grocery store counts per 10,000 population) in the area within 3 km of each respondent's home; coefficients can be interpreted as change in DQI expected from a 1% change in grocery store density.

DQI, diet quality index

Table 1

Future research challenges in large-scale, longitudinal neighborhood environment research

Challenges related to longitudinal data and analysis	
1	How can observational research better control for complex, dynamic sources of bias?
2	What is the appropriate temporal framework for physical activity and diet behaviors, obesity, and related outcomes?
3	What strategies are needed to address residential selectivity in youth, for whom residential choices are made primarily by their parents?
Challenges related to the complexity of communities	
1	What neighborhood area(s) exert the strongest influence on behaviors and obesity?
2	How and why do estimated influences of physical and food environments differ across urbanicity?
3	What are the critical leverage points for reducing inequities in food and physical activity resources?
4	How can community programs enhance existing or improved built environments?
Challenges related to translation of research to effective policies	
1	What additional barriers need to be addressed in specific subgroups
2	What are the most promising policy strategies for reducing childhood obesity?