Published in final edited form as:

Am J Prev Med. 2012 February ; 42(2): 193–199. doi:10.1016/j.amepre.2011.09.029.

Assessing the Built Environment Using Omnidirectional Imagery

Jeffrey S. Wilson, PhD, Cheryl M. Kelly, PhD, Mario Schootman, PhD, Elizabeth A. Baker, PhD, Aniruddha Banerjee, PhD, Morgan Clennin, MPH, and Douglas K. Miller, MD

Department of Geography (Wilson, Banerjee), Indiana University – Purdue University, the Regenstrief Institute, Inc., and Center for Aging Research (Miller), Indiana University, Indianapolis, Indiana, Beth-El College of Nursing and Health Sciences, University of Colorado, Colorado Springs, Colorado (Kelly), the School of Public Health (Baker, Clennin), Saint Louis University, the School of Medicine (Schootman), Washington University, St. Louis, Missouri. Cheryl Kelly was with the School of Public Health at St. Louis University when this research was conducted

Abstract

Background—Observational audits are commonly used in public health research to collect data on built environment characteristics that affect health-related behaviors and outcomes, including physical activity and weight status. However, implementing in-person field audits can be expensive if observations are needed over large or geographically dispersed areas or at multiple points in time. A reliable and more efficient method for observational audits could facilitate extendibility (i.e., expanded geographic and temporal scope) and lead to more standardized assessment that strengthens the ability to compare results across different regions and studies.

Purpose—To evaluate the degree of agreement between field audits and audits derived from interpretation of three types of omnidirectional imagery.

Methods—Street segments from St. Louis and Indianapolis were geographically stratified to ensure representation of neighborhoods with different socioeconomic characteristics in both cities. Audits were conducted in 2008 and 2009 using four methods: field audits, and interpretation of archived imagery, new imagery, and Google Street View imagery. Agreement between field audits and image-based audits was assessed using observed agreement and the prevalence-adjusted bias-adjusted kappa statistic (PABAK). Data analysis was conducted in 2010.

Results—When measuring the agreement between field audits and audits from the different sources of imagery, the mean PABAK statistic for all items on the instrument was 0.78 (archived), 0.80 (new) and 0.81 (Street View imagery), indicating substantial to nearly perfect agreement among methods.

Conclusions—Image-based audits represent a reliable method that can be used in place of field audits to measure several key characteristics of the built environment important to public health research.

© 2011 American Journal of Preventive Medicine. Published by Elsevier Inc. All rights reserved.

Address correspondence to: Jeffrey S. Wilson, PhD, Department of Geography, School of Liberal Arts, Indiana University – Purdue University Indianapolis, 425 University Blvd., Indianapolis IN 46202. jeswilso@iupui.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.

Introduction

Physical inactivity is a leading contributor to the rise of the prevalence of overweight and obesity.¹ While physical activity is influenced by individual and interpersonal factors, researchers are increasingly examining built environment characteristics as potential determinants of physical activity behavior. For example, a 2008 review suggests that mixed land use, shorter distances to nonresidential destinations, and development density are consistent correlates of utilitarian walking among adults.² Researchers have also reported associations between children's participation in physical activity and recreational and pedestrian infrastructure.^{3, 4} Accumulating evidence for built environment effects on physical activity has prompted advocacy for environmental interventions to increase physical activity in communities as a way to counteract the overweight and obesity epidemic.⁵⁻⁷

Despite the emerging evidence base, there are currently several limitations to conducting studies of built environment effects on physical activity. A 2009 review of methods for measuring the built environment identified three general approaches: (1) perceived measures obtained by surveys (e.g., of community residents); (2) extracting objective measures from archival data sets (e.g., census-based GIS data); and (3) systematic observational audits by trained observers.⁸ Each of these methods provides different but complimentary insight into the built environment. However, studies examining detailed observational characteristics of the built environment from the human perspective currently face several challenges.

When comparing perceived versus objective measures of built environment, researchers have reported fair to low levels of agreement between resident perceptions of environmental supports for physical activity and objective measures of these features.⁹ Perceptions are also susceptible to "same-source bias" when the outcome of interest is a self-reported measure such as disability.¹⁰ In-person field audits by trained observers can produce more-reliable results than resident surveys, but they can also be expensive and logistically challenging if observations are needed across large areas, in multiple locations separated by large geographic distances, or at multiple points in time to support longitudinal comparison.^{11,12} Thus, field audits typically have been limited in geographic scope (e.g., to a single neighborhood or city).

Another limitation is that researchers have used different approaches to conduct observational audits.^{2, 13} Measurement inconsistency has been cited as a primary concern because it limits ability to systematically compare results across studies.^{14, 15} Standardized methods using GIS to measure some built environment characteristics have been suggested.¹⁶⁻¹⁸ These approaches are practical for broad-scale implementation, but typically do not provide information about detailed observational environmental characteristics.^{8, 19} For example, GIS databases on physical disorder, condition of pedestrian infrastructure, and environmental aesthetics are not widely available.

The purpose of this study was to evaluate a new method for collecting observational measures of the built environment using omnidirectional imagery. Omnidirectional imagery refers to simultaneous collection of images in multiple directions from a single location, producing a panoramic view (exemplified by Google Street View). This type of imagery provides a permanent visual record of an area and allows observation of characteristics included on many built environment audit instruments. Figure 1 shows a portion of an omnidirectional image from an intersection in St. Louis, MO. Noticeable pedestrian amenities include a sidewalk with ramps, marked crosswalk, signage, a buffer between the sidewalk and street, and a curb bump-out to slow traffic at the intersection. Auditing using omnidirectional imagery may support more efficient and extendable alternatives to field-

based surveys but, given that this is an emerging technology, few studies have reported on the reliability of this approach.

Only three prior studies, to our knowledge, have examined omnidirectional imagery as a tool for built environment auditing.^{20–22} The sample sizes in these studies included 48 streets in Auckland, New Zealand;²⁰ 50 parks in Sydney, Australia;²² and 37 block faces in New York City.²¹ All of these prior studies used publicly available Google Street View imagery, which does not include a time-stamp. Thus, researchers were not able to control for differences in timing of field versus image-based audits. Small sample sizes in these prior studies may also limit variability in presence or absence of built environment characteristics. The current study builds on this previous work using a larger sample of 375 street segments from two different cities representing neighborhoods with different socioeconomic characteristics. The study is also unique in that multiple sources and dates of omnidirectional imagery were evaluated.

Methods

Built environment audits derived from interpretation of three types of omnidirectional imagery were compared to results derived from in-person field audits, the current standard. The three types of imagery evaluated were: (1) imagery collected concurrently with field audits by a commercial provider (new imagery); (2) imagery collected 6–12 months prior to field audits by a commercial provider (archived imagery); and (3) publicly available imagery accessible through Google Street View. The rationale for evaluating both new and archived imagery was to determine if temporal differences affect agreement between field and image audits as a result of seasonal effects or changes in built environment between audit dates. For example, some components of the built environment (e.g., trash or graffiti) may change more rapidly over time, thereby introducing inconsistency in observations conducted on different dates.

The rationale for evaluating both commercial imagery and Google Street View imagery is that Street View presents omnidirectional imagery in a format where the viewer must “hop” to adjacent photographs to view contiguous areas along a street segment. The imagery purchased from a commercial provider was presented in a video format where the user can “slide” along a route to view adjacent areas. The video format is smoother, has better resolution, and is more interactive, but it’s not freely accessible and requires the use of commercial software and more computer storage and processing capacity.

The study was conducted in suburban and urban areas Indianapolis, IN and St. Louis, MO. Street segments were selected in both cities using a geographically stratified sampling design to ensure representation of neighborhoods with different socioeconomic characteristics and to increase heterogeneity in the characteristics of the built environment across street segments included in the sample. Sampling followed a previously established method for geographic stratification using a combination of two race categories (> 50% black and > 50% white) and two income categories based on the percentage of the population in poverty (< 10.0% and ≥20.0%).^{23, 24} Data from the 2000 U.S. Census were used to classify block groups in both cities using this approach (Figure 2).

Street segments were randomly selected for auditing from within four sociodemographic classes proportional to the total number of segments in each class. In total, the current sample included 369 segments (167 in St. Louis and 202 in Indianapolis). Immersive Media Corporation (IMC) was contracted to collect new imagery for the street segments in the current sample. IMC was able to collect imagery successfully for all but 11 segments during July 2008. In addition to the new imagery, IMC previously collected imagery for 217 of the

street segments (59%) in the current sample. This archived imagery was collected in November 2007 in St. Louis and June 2007 in Indianapolis.

Publicly available imagery through Google Street View was also evaluated. Google posted Street View imagery for Indianapolis in November 2007 and for St. Louis in July 2008, but the acquisition dates of Street View imagery were not published. Table 1 summarizes the street segments included in the current analytic sample.

The Active Neighborhood Checklist (i.e., the checklist) was selected as the built environment auditing instrument because it was developed to be practical and serve multiple audiences including researchers, practitioners and communities. The checklist was designed for observation from a pedestrian's perspective.²⁵ This instrument has demonstrated strong inter-rater reliability across items (mean kappa statistics range from 0.61 to 1.00).²⁶ The checklist assesses land use characteristics (predominant land use, land use mix, parking and recreational facilities), sidewalks (sidewalk presence/absence, buffers, continuity, width, curb cuts, misalignments and obstructions), shoulders and bike lanes (shoulder presence/absence, width, continuity, designated bike signs and obstructions), street characteristics (transit stops, number of lanes, crossing aids, traffic-calming devices, speed limit signs) and quality of the environment for pedestrians (building setback, pedestrian amenities, litter, shade trees and slope).

While the Checklist includes many of the characteristics associated with physical activity in the literature, some built environment features were intentionally excluded because they could be assessed easily from existing data sources (e.g., street connectivity with GIS), they vary by time of day (e.g., traffic speed and volume) or they require alternative assessment methods (e.g., social environment). The Checklist and accompanying protocol are accessible via the website of Active Living Research: <http://www.activelivingresearch.org/node/10616>.

The Checklist was used to complete audits for all street segments in the current sample (Table 1). Field audits were completed within 2 months of new imagery collection. To limit same source bias, St. Louis staff conducted field audits in St. Louis, but conducted image interpretation for Indianapolis blinded to that city's field audit results (and vice versa). All auditors were trained to use the Checklist using the protocol developed by Hoehner et al.²⁶

Field and image-based audit results were compared using percentage agreement, the kappa coefficient, and prevalence- and bias-adjusted kappa (PABAK).^{27, 28} Data analysis was conducted in 2010. Hoehler discusses methods for calculating PABAK and the rationale for adjusting the kappa coefficient for prevalence and bias effects.²⁸ Unlike the traditional kappa coefficient, PABAK accounts for systematic differences among data sources and the distribution of each audit item. PABAK has been used as a measure of inter-rater reliability and internal consistency in previous studies of built environment audits.^{29, 30} The following adjectival ratings of Landis and Koch were used to interpret PABAK results: 0.80 to 1.00 (near-perfect agreement), 0.60 to 0.79 (substantial agreement), 0.40 to 0.59 (moderate agreement), 0.20 to 0.39 (fair agreement), and 0.00 to 0.19 (poor agreement).³¹ The Landis and Koch ratings are commonly used in public health research to qualitatively interpret measures of agreement between auditing methods.^{32, 33}

All Checklist items were dichotomized as present or absent. Items that required the auditor to indicate if something was present on one side of the street, both sides of the street or not present, were dichotomized as present (on one or both sides) versus absent. Additionally, ordinal items (i.e., none, some or a lot for litter and tree shading; and flat, moderate or steep for slope) were characterized as present (some or a lot and moderate or steep) versus absent (none or flat). A total of 79 dichotomous variables were included in the analysis. Checklist items pertaining to alternative places to walk, shoulder quality, and presence or absence of a

drinking fountain (items E10 and E13–E16, D2b on Checklist) were excluded from analyses due to lack of variability and missing data.

Results

Archived Imagery Versus Field Audits

When measuring the association between field and archived imagery audits, the mean PABAK for all items in the Checklist was 0.78. Eighty-four percent of the items had substantial or near-perfect agreement (Appendix A, available online at www.ajpmonline.org). Three items pertaining to quality of environment had only fair agreement: presence of litter and broken glass (0.39); other amenity present (0.39); and sidewalk misalignments (0.39). Presence of a sidewalk and the continuity of the sidewalk within and between streets fared well (1.00 and 0.93, respectively) as did presence of a bike route or sign (0.94), shoulders (0.86) and street characteristics (0.86).

New Imagery Versus Field Audits

Similarly, when measuring the agreement between field and new imagery-based audits, the mean PABAK for all items was 0.80. Eighty-seven percent of items had substantial or near-perfect agreement (Appendix B, available online at www.ajpmonline.org). Agreement between field and new image audits of the amount of litter and broken glass improved slightly compared to archived imagery (from fair to moderate). Additionally, presence of a sidewalk (0.99), continuity of the sidewalk (0.88), presence of a bike route (0.95) and shoulders (0.90) and street characteristics (0.89) had near-perfect agreement.

Google Street View Versus Field Audits

The mean PABAK for all items in the Checklist was 0.81 when comparing field audits to audits conducted using Street View. Eighty-six percent of items had substantial or near-perfect agreement (Appendix C, available online at www.ajpmonline.org). Only one item, sidewalk width, fared poorly (0.03), while misalignments had fair agreement (0.23). Similar to archived and new imagery sources, presence of a sidewalk (0.98), continuity of the sidewalk (0.90), presence of a bike route (0.90) and shoulders (0.87) and street characteristics (0.87) had near-perfect agreement. Quality of environment items (litter and broken glass) had moderate agreement (0.45), similar to the new imagery.

Auditing Time

The start and stop time for each audit was recorded by auditors. The average number of minutes to complete each audit type was: field audits –7.31, new imagery –9.02, archived imagery –10.74, and Google Street View imagery –11.08. Travel time for the field audits was not recorded and is not included in these results. However, given that the time to complete field and image-based audits was not vastly different, the logistic benefits of this new method would be most apparent in studies where image-based audits are completed from a single location for segments scattered over a large area (e.g., in a nationwide study) without the cost and time of long-distance travel needed for in-person audits. In the current study, the approximate cost to acquire 28 miles of new imagery and 15 miles of archived imagery was \$15,000; the results indicate that audits using freely accessible Street View imagery were comparable to commercial image sources.

Conclusion

Methods for collecting omnidirectional imagery from stationary locations have been available at least since the early 1990s, but it is only recently that the technology has advanced to a point where omnidirectional imagery is now collected over large areas using

mobile systems. The coverage and availability of this type of imagery is increasing at a rapid pace. For example, Google Street View debuted on the Internet in May 2007 with coverage in five American cities (San Francisco, New York, Las Vegas, Denver, and Miami). As of January 2011, Street View imagery coverage expanded to include thousands of miles of roads in smaller towns and rural areas in the U.S. and international locations including Australia, New Zealand, Japan, South Africa, Brazil and Western Europe. While the majority of Street View imagery is acquired using car-mounted cameras, imagery for some locations not accessible by car is being collected from cycle- and person-mounted cameras. All of this imagery is freely accessible to anyone with a high-speed Internet connection.

The results of the current analysis suggest that using omnidirectional imagery to audit the built environment was comparable to field audits for majority of the characteristics included on the Active Neighborhood Checklist (Figure 2). Regardless of the source of imagery, auditors were able to reliably interpret at least 84% of the characteristics included on the Checklist (substantial to nearly perfect reliability). Characteristics that demonstrated lower level of agreement included items addressing environmental aesthetics (e.g., presence of trash and graffiti) and condition of the sidewalks (e.g., sidewalk width and alignment). However, aesthetics items such as trash and graffiti are consistently less reliable when conducting inter-rater reliability of field auditors because of the subjective nature of these questions.²⁶ While auditors could easily identify if a sidewalk was present, it was difficult to determine the condition and width of the sidewalk from the imagery (regardless of source). A limitation of using imagery is that visual interpretation is limited to the camera's perspective and vantage point so auditors could not view the sidewalks as closely as they would in the field.

Results of this research are similar to previous studies that suggest that omnidirectional imagery offers a viable alternative to field audits that can improve efficiency and extendibility of the observational auditing processes.²⁰⁻²² On average, image-based methods required about 3 minutes longer to complete when compared to field audits. This comparison is based solely on audit time and did not include time associated with travel to and from the street segments. However, agreement between field and image-based audits indicates that image-based approaches offer an efficient alternative, particularly if audits are needed over large or geographically dispersed areas.

A 2005 review of built environment and physical activity research suggests that most studies have been cross-sectional in design and that longitudinal studies are needed to advance knowledge of causal relationships.⁵ Image-based audits have the potential to facilitate longitudinal research by providing a tool to retrospectively audit environmental characteristics using archival imagery, for example before and after a natural experiment occurs. Currently, Google does not provide the ability to view multiple dates of Street View imagery, but this can potentially be included in future implementations, as is the case with aerial photography available in Google Earth. This ability to "go back in time" is an important advantage for longitudinal research that cannot be implemented through in-person approaches. Multi-temporal aerial or satellite imagery is commonly used to detect environmental change, but omnidirectional imagery offers the potential for longitudinal comparison at a finer spatial scale and from a different perspective that may capture features not visible from aerial and satellite platforms.

One issue in using audit data derived from imagery is the temporal relationship of the audits to behaviors or outcomes. This study compared audits derived from imagery that was captured 6–12 months earlier than the field audits, yet the agreement with field audits was similar to the results when using imagery collected concurrently with field audits. In

addition, the current results indicate that publicly available Google Street View imagery appears to work as well as imagery obtained concurrently with field audits.

There are several limitations to this research. This is an exploratory study that, to our knowledge, was the first to evaluate multiple sources of omnidirectional imagery as a resource for conducting built environment audits. Traditional video technologies have been shown to be an effective tool for auditing some built environment characteristics as part of the Project on Human Development in Chicago Neighborhoods,³⁴ but the type of imagery collected by omnidirectional systems is different from traditional video, notably in the interactivity it provides. While omnidirectional imagery provides increased options for viewing the environment from different perspectives, it does not provide complete flexibility to roam around the way that a field auditor can. Rather, the perspective is limited to views from where the imagery was collected (typically from a car driving down the street).

More than 30 field instruments for assessing the built environment have been developed in recent years, but the current study used just one to evaluate the reliability of image-based approaches. The Checklist is a refined version of existing instruments and captures built environment characteristics that are common to many other audit tools. However, other environmental measures not included on the Checklist, such as detailed characteristics of urban green space that may have an impact on physical activity behavior, could be examined in future implementations of this method.

The current study is limited to two Midwestern U.S. cities that have similar characteristics, and it focuses on suburban and urban environments. Other environments (e.g., rural communities) and regions (e.g., coastal and mountain cities) may have built environment characteristics not represented in the current sample. Thus, this approach needs to be tested in other locales to evaluate generalizability. Results of the current study indicate that image-based audits represent a reliable method that can be used in place of field audits to measure several key characteristics of the built environment important to public health researchers.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by the Robert Wood Johnson Foundation through its national program, Active Living Research (ALR), (Grant # 67124). Additional support was provided by a grant from the National Institute on Aging to DKM (R01 AG010436). The authors thank our students at Saint Louis University and Indiana University – Purdue University Indianapolis for their data collection contributions.

No financial disclosures were reported by the authors of this paper.

References

1. Daniels SR, Jacobson MS, McCrindle BW, Eckel RH, Sanner BM. American Heart Association Childhood Obesity Research Summit. Executive Summary. *Circulation*. 2009 ;CIRCULATIONAHA.109.192215.
2. Saelens B, Handy SL. Built Environment Correlates of Walking: A Review. *Medicine & Science in Sports & Exercise*. 2008; 40(7 S1):s550–s566. [PubMed: 18562973]
3. Davison K, Lawson C. Do attributes in the physical environment influence children's physical activity? A review of the literature. *International Journal of Behavioral Nutrition and Physical Activity*. 2006; 3(1):19. [PubMed: 16872543]

4. Grow HM, Saelens BE, Kerr J, DuRant RH, Norman GJ, Sallis J. Where are youth active? Roles of proximity, active transport, and built environment. *Medicine & Science in Sports & Exercise*. 2008; 40(12):2071–2079. [PubMed: 18981942]
5. Transportation Research Board. Examining the Evidence. Washington D.C: National Academies; 2005. Does the Built Environment Influence Physical Activity?.
6. Sallis JF. Measuring Physical Activity Environments: A Brief History. *American Journal of Preventive Medicine*. 2009; 36(4):S86–S92. [PubMed: 19285214]
7. Cheadle AD, Samuels SE, Rauzon S, Yoshida SC, Schwartz PM, Boyle M, et al. Approaches to measuring the extent and impact of environmental change in three California community-level obesity prevention initiatives. *American Journal of Public Health*. 2010; 100(11):2129–2136. [PubMed: 20935262]
8. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the Built Environment for Physical Activity: State of the Science. *American Journal of Preventive Medicine*. 2009; 36(4, Supplement 1):S99–S123.e12. [PubMed: 19285216]
9. Kirtland KA, Porter DE, Addy CL, Neet MJ, Williams JE, Sharpe PA, et al. Environmental measures of physical activity supports: Perception versus reality. *Am J Prev Med*. 2003; 24:323–31. [PubMed: 12726870]
10. Schootman M, Andresen EM, Wolinsky FD, Malmstrom TK, Miller JP, Miller DK. Neighborhood conditions and risk of incident lower-body functional limitations among middle-aged African Americans. *American Journal of Epidemiology*. 2006; 163(5):450–458. [PubMed: 16421245]
11. Brownson RC, Kelly C, Eyler A, Carnoske C, Grost L, Handy S, et al. Environmental and Policy Approaches for Promoting Physical Activity in the U.S.: A Research Agenda. *Journal of Physical Activity & Health*. 2008; 5:488–503. [PubMed: 18648115]
12. Heath G, Brownson RC, Kruger J, Miles R, Powell KE, Ramsey LT, et al. The effectiveness of urban design and land use and transport policies and practices to increase physical activity: A systematic review. *Journal of Physical Activity and Health*. 2006; 3(S1):S55–S76.
13. Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS. The built environment and obesity: A systematic review of the epidemiologic evidence. *Health & Place*. 2010; 16(2):175–190. [PubMed: 19880341]
14. Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: Views from urban planning. *American Journal of Preventive Medicine*. 2002; 23(2, Supplement 1):64–73. [PubMed: 12133739]
15. Papas MA, Alberg AJ, Ewing R, KJH, Gary TL, Klassen AC. The built environment and obesity. *Epidemiologic Reviews*. 2007; 29:129–143. [PubMed: 17533172]
16. Forsyth, A. Environment, Food, and Youth: GIS Protocols, Version 1.3. Minneapolis, MN: University of Minnesota; 2007–2007.
17. Forsyth, A. Environment and Physical Activity: GIS Protocols, Version 4.1. Minneapolis, MN: University of Minnesota; 2007–2007.
18. Forsyth A, Schmitz KH, Oakes M, Zimmerman J, Koepp J. Standards for Environmental Measurement Using GIS: Toward a Protocol for Protocols. *J Physical Activity & Health*. 2006; 3(S1):s241–s257.
19. Day K, Boarnet M, Alfonzo M, Forsyth A. The Irvine-Minnesota Inventory to Measure Built Environments: Development. *American Journal of Preventive Medicine*. 2006; 30(2):144–152. [PubMed: 16459213]
20. Badland HM, Opit S, Witten K, Kearns RA, Mavoa S. Can virtual streetscape audits reliably replace physical streetscape audits? *Journal of Urban Health*. 2010; 87(6):1007–1016. [PubMed: 21104331]
21. Rundle AG, Bader MDM, Richards CA, Neckerman KM, Teitler JO. Using Google Street View to Audit Neighborhood Environments. *American Journal of Preventive Medicine*. 2010; 40(1):94–100. [PubMed: 21146773]
22. Taylor BT, Fernando P, Bauman AE, Williamson A, Craig JC, Redman S. Measuring the Quality of Public Open Space Using Google Earth. *American Journal of Preventive Medicine*. 2010; 40(2):105–112. [PubMed: 21238857]

23. Krieger N. Is breast cancer a disease of affluence, poverty, or both? The case of African American women. *Am J Public Health*. 2002; 92(4):611–3. [PubMed: 11919060]
24. Singh G. Area Deprivation and Widening Inequalities in U.S. Mortality, 1969–1998. *American Journal of Public Health*. 2003; 93(7):1137–1143. [PubMed: 12835199]
25. Hoehner CM, Brennan Ramirez LK, Elliott MB, Handy SL, Brownson RC, Hoehner CM, et al. Perceived and objective environmental measures and physical activity among urban adults. *American Journal of Preventive Medicine*. 2005; 28(2 Suppl 2):105–16. [PubMed: 15694518]
26. Hoehner CM, Ivy A, Ramirez LK, Handy S, Brownson RC. Active neighborhood checklist: a user-friendly and reliable tool for assessing activity friendliness. *Am J Health Promot*. 2007; 21(6): 534–7. [PubMed: 17674642]
27. Byrt T, Bishop J, Carlin JB. Bias, prevalence and kappa. *Journal of Clinical Epidemiology*. 1993; 46:423–429. [PubMed: 8501467]
28. Hoehler FK. Bias and prevalence effects on kappa viewed in terms of sensitivity and specificity. *Journal of Clinical Epidemiology*. 2000; 53:499–503. [PubMed: 10812322]
29. Seymour M, Reynolds KD, Wolch J. Reliability of an Audit Tool for Systematic Assessment of Urban Alleyways. *Journal of Physical Activity & Health*. 2010; 7(2):214–223. [PubMed: 20484760]
30. Fisher BD, Richardson S, Hosler AS. Reliability Test of an Established Pedestrian Environment Audit in Rural Settings. *American Journal of Health Promotion*. 2010; 25(2):134–137. [PubMed: 21039295]
31. Landis J, Koch G. The measurement of observer agreement for categorical data. *Biometrics*. 1977; 33:159–174. [PubMed: 843571]
32. Troped, PJ.; Cromley, EK.; Fragala, MS.; Melly, SJ.; Hasbrouck, HH.; Gortmaker, SL., et al. *Journal of Physical Activity & Health*. Vol. 3. 2006. Development and reliability and validity testing of an audit tool for trail/path characteristics: the Pathe Environment Audit Tool (PEAT); p. S158-S175.
33. Brownson RC, Chang JJ, Eyler AA, Ainsworth BE, Kirtland KA, Saelens BE, et al. Measuring the environment for friendliness toward physical activity: a comparison of the reliability of 3 questionnaires. *American Journal of Public Health*. 2004; 94(3):473–483. [PubMed: 14998817]
34. Sampson RJ, Raubenbush SW. Systematic social observation of public spaces: A new look at disorder in urban neighborhoods. *American Journal of Sociology*. 1999; 105(3):603–51.

Figure 1.

A portion of an omnidirectional image depicting a street intersection in St. Louis

Note: Noticeable pedestrian amenities include a sidewalk with ramps, marked crosswalk, signage, a vegetated buffer between the sidewalk and street, and a curb bump-out to slow traffic at the intersection.

Figure 2.
Geographic stratification of census block groups in St. Louis (left) and Indianapolis (right)
Note: Street segments were sampled from the four “corner” classes in the legend.

Figure 3.

Comparison of PABAK statics by built environment domain for all imagery sources

Note: A higher score means greater agreement. PABAK, prevalence-adjusted, bias-adjusted kappa statistic

Table 1
Street segments analyzed in Indianapolis and St. Louis (combined), number of segments (miles)

Socioeconomic Category, %	Type of imagery		
	Archived	New	Street view
≥50 black	63 (4.83)	100 (7.71)	96 (7.33)
≥20 poverty			
≥50 black	11 (1.04)	48(4.25)	48 (4.25)
<10 poverty			
≥50 white	108 (5.80)	145 (9.42)	150 (9.76)
≥20 poverty			
≥50 white	35 (3.22)	65 (6.85)	64 (6.80)
<10 poverty			
Totals	217–14.90	358–28.22	358–28.14

Note: All analyses were based on field audits combined with imagery type as shown.