4-2004

Monitoring Physical Activity: Uses and Measurement Issues With Automated Counters

Michelle L. Granner

Patricia A. Sharpe
University of South Carolina - Columbia, SHARPEP@mailbox.sc.edu

Publication Info

Published in *Journal of Physical Activity and Health*, Volume 1, Issue 2, 2004, pages 131-141.
Granner, M. L., & Sharpe, P. A. (2004). Monitoring physical activity: Uses and measurement issues with automated counters. *Journal of Physical Activity and Health, 1*(2), 131-141.

Journal of Physical Activity and Health, 2004, 1, 131-141

Monitoring Physical Activity: Uses and Measurement Issues With Automated Counters

Michelle L. Granner and Patricia A. Sharpe

Background: Promotion of physical activity is a public health priority, and environmental factors influence physical activity behavior. Valid and reliable automated measurement tools of physical activity for assessment and evaluation within public settings are needed. *Methods:* Searches of the research literature and governmental reports from physical activity, transportation, and recreation fields were conducted to identify methods of automated counting and validation studies. The article provides a summary of (a) current methods and uses of automated counters, (b) information about validity and reliability where available, (c) strengths and limitations of each method, and (d) measurement issues. *Results:* Existing automated counting technology has strengths and limitations. Infrared sensors have been the most commonly used type of monitor and can mark date and time of passage, but are vulnerable to errors due to environmental conditions; cannot detect more than one person passing at a time; cannot identify mode of activity or distinguish among individuals; and lack consistent and adequate reliability for use in open spaces. Seismic devices and inductive loops may be useful for specific applications. More information is needed concerning the validity and reliability of infrared sensors, seismic devices, and inductive loops for confined areas. Computer imaging systems hold potential to address some of the limitations of other automated counters and for applications in both confined and open areas, but validation research is in the initial stages. *Conclusions:* Although automated monitoring is a promising method for measurement of physical activity, more research is necessary to determine the acceptable parameters of performance for each type of automated monitor and for which applications each is best suited.

Key Words: exercise, measurement, environment, infrared sensor, public facilities

The authors are with the Prevention Research Center in the Norman J. Arnold School of Public Health at the University of South Carolina, Columbia, SC 29208. In addition, Sharpe is with the Department of Exercise Science at the University of South Carolina.

Introduction

As reflected by a growing literature of the physical environment's influence on physical activity,[1–13] there is recognition of the need for systematic environment and policy research, interventions, and advocacy action to promote population-wide physical activity.[10,14] In order to effectively and accurately assess the importance and use of environmental resources for physical activity, as well as to evaluate the impact of interventions, rigorous, standardized research methods and valid and reliable measures are required.[10,15]

Macro-level approaches to physical activity promotion and surveillance require automated methods of measuring physical activity in the built and natural environments, including stairwells, walking trails, parks and recreation areas, sidewalks, and cycling lanes. Automated counting or monitoring refers to an objective measurement device that can, at minimum, provide automated counts of passages through a specified area (e.g., number of passages of pedestrians or bicyclists at a point on a trail). There are several categories of automated monitors, including seismic and piezoelectric devices, inductive loops, infrared sensors, and computer imaging systems.

This paper provides an overview of automated monitoring devices and applications, including strengths and limitations of specific types of monitoring devices, as reported in the research and practice literature. When available, information about validity and reliability is summarized. Finally, the paper provides a summary of measurement issues in automated monitoring, with recommendations to advance the field.

Overview of Uses and Methods of Automated Monitoring

General Applications of Automated Monitoring

Automated monitoring is a potentially valuable source of systematic, objective, and relatively cost-effective data collection. Much of automated monitoring has occurred in the transportation and recreation fields. Pedestrian and bicycle counts have many potential uses for transportation planning, including estimating overall usage; tracking trends in use; forecasting demand; analyzing safety and crash prevention; improving safety and optimizing efficiency of street crossings; evaluating level of service; identifying and prioritizing improvements; and tracking effectiveness of policies, programs, and facility improvements.[14,16] In addition, counts may be used as a proxy measure of the attractiveness of the area or facility.[17] Data regarding volume of use and associated information can also be gathered, including user characteristics, mode of travel, trip distance, time of day, and day of the week.[14]

Automated monitoring also has numerous potential applications related to recreation and has been reported to be a flexible and inexpensive method of measuring trail use.[18–21] Common uses of automated counts in recreation include determining resource use, determining staff needs, allocating budget, justifying grants and capital development, assessing the economic impact of resources and policies, and informing policy and other managerial decisions.[18,20–22] Data can also be used to plan the building and location of new trails, as well as the enhancement of

existing trails, by predicted level of use.[18,21–23] Counts also can be used for the management, maintenance, and allocation of natural resources and for assessing potential impacts of human use on wildlife and plants.[18,20–23] Further, trail counts can provide information about frequency and duration of use, trends in use, impacts of improvements and interventions, and community benefits.[18,20–23]

Applications of Automated Monitoring for Physical Activity Research

There are many potential uses of automated monitoring for physical activity, including assessing levels of physical activity (mode, frequency, and duration); assessing active transportation behaviors; assessing use of facilities and environmental supports; planning and evaluating interventions; assessing the impact of social, behavioral, environmental, and policy supports; justifying the need for funding or building facilities; and enhancing the ability to link and supplement objective data with other database sources (e.g., Geographical Information Systems, Global Positioning Systems) and self-reports. Currently available monitoring technology systems, however, may not yet be versatile, comprehensive, and accurate enough for this range of potential uses. To date, there has been very little use of automated monitoring for physical activity promotion and surveillance.[15,24,25]

Categories of Automated Monitoring: Strengths and Limitations

Table 1 provides a summary of the strengths and limitations of the different types of automated counters or monitors. Seismic and piezoelectric devices sense vibrations or pressure and can be in the form of plates, mats, tubes, or spikes (geophones with a spike on one end to stick into the ground).[19,20] Inductive loop counters sense impulses or disruptions in an electrical field when an individual or object passes over the loop.[20] There are two types of infrared sensors: passive and active. Passive counters detect a moving object's infrared emissions (body heat and motion). Active infrared counters send a beam across a measurement zone, recording a count when the beam is interrupted.[19,20] Computer imaging uses either cameras or microprocessors to track individuals passing through a measurement zone.[26–28] Any of the counter types can be paired with a video camera or human observers for validation.

Seismic Devices and Piezoelectric Mats

Little information regarding the use, accuracy, and reliability of seismic devices and piezoelectric mats has been published. Seismic systems are vulnerable to changes in soil conditions and differences in body weight, but may be less susceptible to vandalism than other counter types because they are buried underground.[19–21] Seismic units with a mat or tube sensor are preferred over spike sensors, which produce less accurate counts.[19] Mats can be used to count pedestrians and cyclists, but may be vulnerable to errors from environmental conditions like snow cover or vibrations due to wind[20] and therefore may be best suited for indoor use.[21] The size of the measurement zone is an important consideration—too small a zone risks losing valid counts and too large a zone risks double counts. Time-delay activation

Table 1 Summary of Automated Monitors' Strengths and Limitations

Type of monitor	Available validity and reliability	Strengths	Limitations
Seismic devices and piezoelectric mats	None available at this time	Little concern of vandalism	Difficult to calibrate; vulnerable to errors related to soil conditions, varying body weights, & environmental conditions; size of sensing zone; use of time-delay detection; may be unsuitable for high traffic areas; cannot identify mode of activity; cannot distinguish among individuals.
Inductive or magnetic loops	None available at this time	Little concern of vandalism	Triggered by metal; cannot identify mode of activity; cannot distinguish among individuals.
Active and passive infrared sensors	Over-estimated people using walking path 14–78%; walking path volume ranged from 20% underestimation to 16% overestimation, with underestimated park use 0–69%.[15] Systematic 15% underestimation of trail use.[30]	Relatively easy set-up and relocation. Specific to active Infrared: narrow detection zone.	Dependent on height placement; concern of vandalism; use of time-delay detection; cannot detect simultaneous, multiple passages; cannot identify mode of activity; cannot distinguish among individuals. Specific to passive infrared: vulnerable to errors with reflective clothing, background fluctuations, weather, and animals. Specific to active infrared: more difficult relocation.
Video with computer processing	70% agreement with observation (open environment).[13] 85% agreement with observation (open environment).[31] 2% difference from observation (confined area).[26]	Identify mode of activity; distinguish among individuals; better able to detect simultaneous, multiple passages; flexible long-term use; monitor larger spaces.	Greatest effort for initial setup and calibration; concern of vandalism; may be sensitive to fluctuations of light or shadow.

may be used to program the time required for one individual to pass through the zone before another count can be registered;[19] however, this time delay may miss other individuals who pass through the zone during that period of time, making these counters unsuitable for high traffic areas. In other words, if the measurement zone is 6’ × 6’ × 6’ and time-delay activation is not used, the same person will be counted at least twice within this zone (for each footfall). If time delay–activation is used, and there are two (or more) people passing through this zone at the same time, only one of these people will be counted.

Inductive or Magnetic Loops

Like seismic devices, inductive loop counters can also be buried, reducing concerns of vandalism, and will work on paved or unpaved roads, but are most easily triggered by metal objects that cause disruptions in the electrical field and are thus best suited to counting automobiles or bicycles rather than pedestrians or in-line skaters.[16,21] Detection of bicycles by loops has been shown to be independent of a bicycle’s speed, position, and movement angle; however, a loop’s winding pattern (the loop area and number of turns are directly proportional to its sensitivity), shape, and size are all factors that affect performance.[16]

Infrared Sensors

The three most commonly used automated counters reported from the recreation literature were infrared counters, inductive loops, and seismic devices.[20,21] Infrared sensors were the most common automated devices employed, but users perceived infrared sensors, as well as inductive loops and seismic devices, to be only moderately effective.[18] One study conducted a simulated evaluation of three types of trail counters—active infrared, passive infrared, and seismic monitors. Situations that often result in inaccurate counts, such as closely spaced groups, people with body weights either heavier or lighter than average, light and reflective clothing, and dark and matte clothing were used to test each monitor type. Active infrared counters demonstrated the best validity of the three types tested.[19]

Infrared sensors have been the counter of choice for automated monitoring because of their relative ease of installation and use; however, infrared sensors have several important limitations. Active infrared counters have some advantages over passive infrared counters, including a narrower measurement zone and less susceptibility to errors in counting caused by reflective clothing.[19] Active infrared counters cannot be as easily relocated as passive counters, and the sensor and reflector of active counters should be located within 100 feet of each other.[20,21] Passive infrared counters are not as reliable as active counters due to their larger detection zones and tendency to produce miscounts due to animals, passage of groups of people, background fluctuations, shadows, and weather. Passive counters are not recommended unless used as a trigger for a camera.[19,21]

Careful site selection and installation are critical to obtaining accurate counts.[18] Active infrared beams should be placed at waist level to avoid counting animals, and areas where people stop and move back and forth should be avoided. Vandalism is another concern.[15,19,20] Active infrared counters can be programmed to minimize false counts from certain objects (e.g., falling leaves) so that the beam must be blocked for a certain amount of time to register a count, and there is a time-delay before the next count can be detected (eliminating double counting).[19] As

with seismic devices, using a time-delay increases the risk of missing other people passing through the measurement zone during that time period.

Infrared sensors are less expensive than computer imaging systems, but are not as flexible and are not reliable for large areas or in high traffic areas, particularly where volume is irregular or people pass close together.[26,29] In addition, although infrared sensors can record date and time of events, they cannot identify mode of travel, distinguish between or track specific individuals, or measure the direction of motion.[23,26,30]

Three studies found that active infrared counters were particularly vulnerable to errors when used in outdoor settings.[15,23,30] One 4-month study reported that the counter "represented a systematic 15% undercount of trail users."[30] Another study comparing infrared beam counters and direct observation of walking path and overall park use found the infrared beam over-estimated the number of people using the walking path by 14–78% and underestimated park use by 0–69%. Further, user volume assessed by the infrared beam ranged from 20% under-estimation to 16% over-estimation.[15] This wide range of inaccuracy may be attributed to the inconsistency of the infrared counter in measurement—double counts, false counts, and an inability to distinguish between individuals can lead to overestimation; while simultaneous passage of two or more people, time-delay activation, and monitor placement (both height and location, as well as multiple entry points) can lead to underestimation.[15,23,30] Based on these results, infrared beams appear to be unreliable and inappropriate for measuring physical activity in outdoor, open areas, and areas with multiple entry points, like parks. Placing counters at each entry/exit point may partially address this issue. However, the more difficult and major limitations of the infrared beam are its inability to distinguish between total user volume and specific individuals, its inability to count more than one passage at a time, its being vulnerable to making false counts, and its dependence on height placement.[15,23]

Video Images With Computer Processing Systems

Systems that use computer processing of video images are currently the most comprehensive automated monitoring method for long-term monitoring.[29] Systems use some type of video camera to monitor an area, and the computer, programmed with specific algorithms to enable recognition of an individual or object, tracks and counts the images. Algorithms can be developed to account for fluctuations in light and shadow,[31] as well as to track pedestrians and bicyclists. Privacy issues can be addressed by blurring the images so that individuals cannot be identified; further, the computer does not need to store the images in order to count individuals. As such, computer systems can directly detect and count events or passages and may improve the reliability and accuracy of observation, as well as improve the efficiency of data collection and analysis.[27] Further, imaging systems hold potential to provide additional information over and above other types of automated counters, such as tracking individual users and identifying and distinguishing mode of activity. Imaging systems may be less intrusive and more mobile than other automated methods.[13,21]

Primary factors affecting reliability are proper setup and maintenance. Considerations for installation include protecting privacy, location (e.g., with adequate traffic), unobstructed view, aim and focus, frame exposure rate, and vandalism.[20,21]

Continuous monitoring should provide the highest level of validity and reliability both in terms of detection of all users and variations in use patterns by hour, day, week, month, or year. If systems will not be monitoring continuously, then detection of motion and activation of the counter needs to be specially calibrated. There are some general strategies for calibration if monitoring is not continuous. One is to run the system for a specified time interval, in which case random sampling of time intervals should be used. The second method is to use another automated counter, such as an infrared beam, to activate the system. This method does not account for error occurring because users were undetected by the other counter.[21]

A study of bicycle counting using grey scale images produced by a time-lapse video camera and analyzed in real-time was found to agree 70% with visual review of the video for a variety of weather conditions. The system was also able to count vehicles, pedestrians, and skaters. As with pedestrians, one difficulty in obtaining accurate counts was overlapping bicycles. The average performance of the system was eight frames per second (tested with two bicycles and four other objects tracked per image).[13] Specific challenges to bicycle monitoring included the ability to distinguish a bicycle from the environment and from other objects, as well as speed of detection for real-time processing.[13]

Characteristics of the space monitored can have a major effect upon the accuracy of the monitoring system. Generally, confined spaces are less problematic than more open, unconfined areas. A study of bus use employed video image sequence analysis by tracking occlusions of the bus' steps as individuals entered the bus. Tracking occlusions of a stationary object (bus' steps) allowed for more accurate counting even when light conditions fluctuated. Automated counting by this imaging system differed from visual review of the tape by about 2%.[26] In comparison, Sexton and colleagues investigated if automated bi-directional counting of pedestrians in unconstrained areas could be reliable and economically feasible.[31] Open areas in a passenger train station were monitored for 12–30 min. Two sites were chosen—one that provided mostly natural light and the other artificial light (both with variations in light and shadow). Although the artificial light site was tested only once, there was generally less error for the artificial compared to the natural light setting (7% vs. 1–21%, respectively). Total volume error rates ranged from 1.5–14%, and mean total volume error was 9.3%. Average error for inflow (moving toward the system) was 13.6% and for outflow was 9.3%. This system was able to provide a bi-directional counting accuracy of better than 85% for 15–30 min time intervals. High traffic (in terms of high numbers of individuals passing by at the same time) caused some problems in tracking and counting pedestrians because it slowed the processing rate (down to 5–6 frames/s).[30] High traffic of this kind poses a threat to the validity and reliability of all current automated monitors, although some counter types or configurations, particularly computer imaging, appear to be better able to handle this than other types.

General Concerns Related to Testing and Validation of Automated Monitoring Systems

Manual or direct human counts of behavior have been a "gold standard" for observing physical activity behavior. Manual counts can be relatively inexpensive if required only for short time periods,[29] but more systematic and reliable counts with human observers are time and cost intensive;[14,21] and observer error, fatigue,

and reactivity limit the utility of long-term observation. Once automated monitors demonstrate validity and reliability, they may provide a relatively time- and cost-effective alternative, objective method of surveillance. Until then, direct observation remains the standard against which automated counts are compared.[15,20,21,30] Careful planning, training, and supervision of observers minimizes threats to reliability and validity of human observer counts. A detailed discussion of the methodology and validity of direct human observation is beyond the scope of this paper, but several sources discuss these issues in detail.[20,21,32–34]

Study design for validation of automated monitoring systems should consider sampling monitoring time periods; collecting enough samples to account for daily, weekly, and seasonal variations; and varying data collection schedules to account for variations in weather, special events, or other causes.[14] Methods should be applied systematically to provide either continuous sampling or careful random or stratified random sampling.[20] Choice of observation sites is an important variable in determining pedestrian volume.[29] Rotation of equipment location is also an important factor to consider, in that the amount of time a location is monitored should correspond to the expected volume and timing of use.[20] Pedestrian volume varies by regular daily, weekly, monthly, and yearly cycles, as well as by location.[17] Therefore, when volumes of pedestrians are used to follow trends, it is important to select matched sampling days (same date, times, etc.).[17]

Issues to consider when choosing a monitoring site include accessibility (i.e., central location), different community populations and community types, geographic locations, and different types of facilities (i.e., paved or dirt trail, length of trail).[28] Count sites should be in areas where there is relatively consistent activity to produce more reliable results. In addition, counts should be taken at peak activity times, which are usually linked to good weather and longer hours of daylight.[29] Because walking trips vary more than motor vehicle volume, 1-day counts are unlikely to provide statistically reliable results. The weather impacts daily pedestrian flows more so than for motor vehicles; and cycling trips may be more variable over time compared to walking trips.[29]

Installation sites should be assessed for objects obstructing view and slope. Counters should be housed in weather- and wildlife-resistant structures.[20] Maintenance should be performed regularly and should consider battery life, data storage capacity, ease and convenience of downloading data, potential for equipment failure, vandalism/theft, and counter rotation schedules.[20] The system should be sturdily mounted and be able to handle vibrations, lighting fluctuations, and variations in the environment;[20,23,26] therefore, systems should be tested under various weather and other environmental conditions, including wind, vibrations, snow/rain/fog (reduced visibility), snow/rain (wet/snow covered pavement), direct sunlight, shadows, temperature extremes, and temperature/humidity, as well as for different mounting configurations (height and mounting overhead or to the side).[16]

Further development and evaluation is necessary for all counter types.[10,14] General sources of potential error across monitoring systems include not being able to differentiate wildlife from individuals and sensitivity of detection.[20] Pedestrian movements are disorganized and complex, presenting several challenges for accurate automated counting, including bi-directional walkways, bumping or nudging between pedestrians, wide variations in speed, ability to change speeds quickly, ability to change and form lanes on the walkway, walking side-by-side, and walking in clusters.[35] Some of these pedestrian configurations (in particular the latter

two) are not accurately counted by existing automated monitors, and with a large number of pedestrians, it may be almost impossible to account for or quantify these configurations (leading to an unknown level of uncertainty).[31] In addition, shadows and global light fluctuations may present an uncontrollable amount of error.[28] With existing technology, systems should not be placed in wide areas, where people can walk two or three abreast, or in natural resting places, where stopping and moving back and forth will result in inaccurate counts;[20] however, future development should be able to address these and other weaknesses of these systems.

Summary and Conclusions

Each type of existing automated monitoring system has strengths and limitations. Seismic devices and inductive loops may be beneficial for certain measurement applications, but more research is needed to establish the validity and reliability of these methods for each potential application. Infrared sensors are not valid measures in open, unconfined areas. More research is necessary to determine if infrared sensors demonstrate adequate validity and reliability for measurement of physical activity in confined spaces such as stairwells. Computer imaging systems have potential for wide application for a multitude of needs and have the potential to address, or at least dramatically improve upon, several of the limitations of other automated methods, such as counting multiple people passing through the sensing zone at the same time, distinguishing among individual users, and identifying and distinguishing mode of activity. Continued attention to and new ways of addressing privacy concerns with these systems is necessary. More research is needed to determine if imaging systems are able to demonstrate adequate validity in both open and confined areas. Recent technological advances and increasing access and availability of these technologies will make imaging systems more affordable. Further development and research of these systems should enhance validity and reliability, as well as their ability to address methodological or logistic concerns that cannot be addressed by other types of automated monitors. For instance, imaging systems could be developed to track individuals to evaluate frequency and duration of physical activity and, under certain conditions, could estimate intensity of physical activity (i.e., time to complete a lap around a track/trail). Automated monitors may provide a relatively cost-effective and objective measure of physical activity behavior that can be applied to a variety of objectives; however, further research is required to test the performance of these monitors in a variety of situations and to guide modification or further development.

References

1. Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: views from urban planning. *Am J Prev Med*. 2002;23(suppl 2):64-73.
2. Carnegie MA, Bauman A, Marshall AL, Mohsin M, Westley-Wise V, Booth ML. Perceptions of the physical environment, stage of change for physical activity, and walking among Australian adults. *Res Q Exerc Sport*. 2002;73:146-155.
3. Berrigan D, Troiano RP. The association between urban form and physical activity in U.S. adults. *Am J Prev Med*. 2002;23(suppl 2):74-79.

4. Craig CL, Brownson RC, Cragg SE, Dunn AL. Exploring the effect of the environment on physical activity: a study examining walking to work. *Am J Prev Med*. 2002;23(suppl 2):36-43.
5. Brownson, RC, Housemann RA, Brown DR, Jackson-Thompson J, King AC, Malone BR, Sallis JF. Promoting physical activity in rural communities: walking trail access, use, and effects. *Am J Prev Med*. 2000;18:235-241.
6. Sallis JF, Johnson MF, Calfas KJ, Caparosa S, Nichols JF. Assessing perceived physical environmental variables that may influence physical activity. *Res Q Exerc Sport*. 1997;68:345-351.
7. Booth ML, Owen, N, Bauman A, Clavisi O, Leslie E. Social-cognitive and perceived environment influences associated with physical activity in older Australians. *Prev Med*. 2000;31:15-22.
8. Troped PJ, Saunders RP, Pate RR, Reininger B, Ureda JR, Thompson SJ. Associations between self-reported and objective physical environmental factors and use of a community rail-trail. *Prev Med*. 2001;32:191-200.
9. Brownson RC, Baker EA, Housemann RA, Brennan LK, Bacak SJ. Environmental and policy determinants of physical activity in the United States. *Am J Public Health*. 2001;91:1995-2003.
10. Sallis JF, Bauman A, Pratt M. Environmental and policy interventions to promote physical activity. *Am J Prev Med*. 1998;15:379-397.
11. King AC, Castro C, Wilcox S, Eyler AA, Sallis JF, Brownson RC. Personal and environmental factors associated with physical inactivity among different racial-ethnic groups of US middle-aged and older-aged women. *Health Psychol*. 2000;19:354-364.
12. King AC, Jeffery RW, Fridinger F, Dusenbury L, Provence S, Hedlund SA, Spangler K. Environmental and policy approaches to cardiovascular disease prevention through physical activity: issues and opportunities. *Health Educ Q*. 1995;22:499-511.
13. Rogers S, Papanikolopoulos NK. *Bicycle Counter: Final Report*. St. Paul, Minn: Minnesota Department of Transportation, Office of Research & Strategic Services; March 2000.
14. U.S. Department of Transportation, Bureau of Transportation Statistics. Bicycle and pedestrian data: sources, needs, & gaps. BTS00-02 Washington, DC; 2000.
15. Milat AJ, Stubbs J, Engelhard S, Weston P, Giles-Corti B, Fitzgerald S. Measuring physical activity in public open space—an electronic device versus direct observation. *Aust N Z J Public Health*. 2002;26:50-51.
16. Minnesota Department of Transportation and SRF Consulting Group: For USDOT and Federal Highway Administration. *Bicycle and Pedestrian Detection: Draft—Evaluation Test Plan*; March 2001.
17. Monheim R. Methodological aspects of surveying the volume, structure, activities, and perceptions of city center visitors. *GeoJournal*. 1998;45:273-287.
18. Lynch J, Vogt C, Cindrity S, Nelson C. *Measuring and Monitoring Trail Use: A Nationwide Survey of State and Federal Trail Use Managers*. East Lansing, MI: Department of Park, Recreation, and Tourism Resources, Michigan State University; January 2002. Available from: http://www.prr.msu.edu/trails/Reports/TRMANAGER SURVEY2.pdf.
19. Gasdova D. *Trail Traffic Counters: Update*. Document No. 9924-2835-MTDC, Missoula, MT: U.S. Department of Agriculture and The Forest Service, Technology & Development Program; September 1999. Available from: http://www.fhwa.dot.gov/environment/fspubs/99232835/992835hi.pdf.
20. Watson AE, Cole DN, Turner DL, Reynolds PS. *Wilderness Recreation Use Estimation: A Handbook of Methods and Systems*. General Technical Report RMRS-GTR-56. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station; 2000. Available from: http://leopold.wilderness.net/pubs/409.pdf.

21. Yuan S, Maiorano B, Yuan M, Kocis SM, Hoshide GT. *Techniques and Equipment for Gathering Visitor Use Data on Recreation Sites*. USFS 2300 Recreation 9523-2838-MTDC. Missoula, MT: USDA Forest Service, Technology & Development Program; 1995.
22. Loomis JB. Counting on recreation use data: a call for long-term monitoring. *J Leisure Res*. 2000;32:93-96.
23. National Park Service. *Trail Count Report: 2000–2001*. Available from: http://www.nps.gov/pinn/pdffiles/trailmaster.pdf. Accessed July 1, 2002.
24. Centers for Disease Control and Prevention, Division of Nutrition and Physical Activity. Available from: http://www.cdc.gov/nccdphp/dnpa/stairwell. Accessed July 1, 2002.
25. Neff LJ, Ainsworth BE, Wheeler FC, Krumweide SE, Trepal AJ. Assessment of trail use in a community park. *Fam Community Health.* 2000;23(3):76-84.
26. Bartolini F, Cappellini V, Mecocci A. Counting people getting in and out of a bus by real-time image-sequence processing. *Image and Vision Computing.* 1994;12:36-41.
27. Kahng S, Iwata BA. Computerized systems for collecting real-time observational data. *J Appl Behav Anal*. 1998;31:253-261.
28. Kehtarnavaz N, Rajkotwala F. Real-time vision-based detection of waiting pedestrians. *Real-time Imaging.* 1997;3:433-440.
29. UK Department of Transport, Charging and Local Transport Division. *Monitoring Walking*. Available from: http://www.roads.dft.gov.uk/roadnetwork/ditm/tal/walking/06_00. Accessed July 31, 2000.
30. Wolter SA, Lindsey G. *Summary Report Indiana Trails Study: A Study of Trails in 6 Indiana Cities*. Bloomington, Ind: Eppley Institute for Parks & Public Lands, Indiana University; 2001. Available from: http://www.state.in.us/dot/projects/trails/z-CompleteDocument.pdf.
31. Sexton G, Zhang X, Redpath G, Greaves D. Advances in automated pedestrian counting. Available from: http://www.unn.ac.uk/~epgs1/publications/ecos95/ecos95.htm. Accessed July 1, 2002.
32. McKenzie TL. The use of direct observation to assess physical activity. In: Welk G, ed. *Physical Activity Assessments for Health-Related Research*. Champaign, Ill: Human Kinetics; 2002:179-195.
33. Cone JD. Observational assessment: measure development and research issues. In: Kendall PC, Butcher JN, Holmbeck GN, eds. *Handbook of Research Methods in Clinical Psychology.* 2nd ed. New York: John Wiley & Sons; 1999:183-223.
34. Engelhard S, Stubbs S, Weston P, Fitzgerald S, Giles-Corti B, Milat AJ, Honeysett D. Methodological considerations when conducting direct observation in an outdoor environment: our experience in local parks. *Aust N Z J Public Health.* 2001;25:149-151.
35. Blue VJ, Adler JL. Cellular automata microsimulation for modeling bi-directional pedestrian walkways. *Transportation Res Part B.* 2001;35:293-312.

Acknowledgments

The authors appreciate the comments of Regina Fields, MS, and Malcolm Kudra on an earlier version of this manuscript. This article was supported in part by Grant Number 047333 from Robert Wood Johnson Foundation's Active Living Research Program and Cooperative Agreement Number U48/CCU409664 from the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Robert Wood Johnson Foundation.