Published in final edited form as:

J Phys Act Health. 2012 August ; 9(6): 809–817.

Comparison of Home and Away-From-Home Physical Activity Using Accelerometers and Cellular Network–Based Tracking Devices

Pradeep Y. Ramulu, Emilie S. Chan, Tara L. Loyd, Luigi Ferrucci, and David S. Friedman

Ramulu, Chan, Loyd, and Friedman are with the Wilmer Eye Institute, Johns Hopkins University, Baltimore, MD. Ferrucci is with the Longitudinal Studies Section, Clinical Research Branch, National Institute on Aging, Bethesda, MD.

Abstract

Background: Measuring physical at home and away from home is essential for assessing health and well-being, and could help design interventions to increase physical activity. Here, we describe how physical activity at home and away from home can be quantified by combining information from cellular network–based tracking devices and accelerometers.

Methods: Thirty-five working adults wore a cellular network–based tracking device and an accelerometer for 6 consecutive days and logged their travel away from home. Performance of the tracking device was determined using the travel log for reference. Tracking device and accelerometer data were merged to compare physical activity at home and away from home.

Results: The tracking device detected 98.6% of all away-from-home excursions, accurately measured time away from home and demonstrated few prolonged signal drop-out periods. Most physical activity took place away from home on weekdays, but not on weekends. Subjects were more physically active per unit of time while away from home, particularly on weekends.

Conclusions: Cellular network–based tracking devices represent an alternative to global positioning systems for tracking location, and provide information easily integrated with accelerometers to determine where physical activity takes place. Promoting greater time spent away from home may increase physical activity.

Keywords

outdoors; measurement; built environment; geographic information systems

Physical activity and travel outside the home are both significant predictors of health and well-being.¹ Adults who perform less physical activity report a lower quality of life² and are more likely to have serious comorbid conditions such as coronary artery disease,³ diabetes,⁴ and osteoporosis.⁵ Additionally, several studies have demonstrated an association between physical activity and mortality.^{6–12} Individuals who travel away from home less have more difficulties with the activities of daily living¹³ and a greater risk of frailty.¹⁴

The importance of both physical activity and travel away from home has led to efforts to compare how physically active individuals are in different regions of their lived environment.^{15–21} Such work has the ability to identify “obesogenic” environments which

discourage physical activity, and could lead to individual-based and community-based strategies for improving physical activity. Prior studies on this topic have all used accelerometers to directly measure the amount and intensity of physical activity over the time of day, and global positioning system (GPS) devices to specify the individual's location.

However, despite the incredible accuracy of GPS devices, they are still limited in providing location over the full course of a normal day. GPS devices require “open sky” overhead, and localize individuals very poorly indoors. As such, several studies have restricted their analysis of physical activity to time spent outside.^{15–18,22} Other studies have attempted to correlate physical activity with location over the full course of the day, but have had to deal with large amounts of missing location data.^{19,20} Besides its shortcomings indoors, GPS failure can also occur outdoors for many reasons (tall urban structures, inside vehicles, improper device orientation, battery failure).^{23–26} Indeed, a study which used accelerometer and GPS devices to determine physical activity associated with home to work transportation could only collect suitable GPS data for 11% of commutes.¹⁷

Numerous devices have recently become commercially available which provide location based on the cellular network. Unlike GPS-based devices, devices relying on the cellular network can provide localization wherever cellular reception is available. As such, these devices work in most outdoor and indoor locations. One study has used cellular technology to follow adolescent travel patterns over a 1-week period.^{27,28} However, little is known about how accurately and reliably these cellular devices provide location.

Here, we conduct a study to evaluate the function of a cellular network–based tracking device with regards to spatial accuracy, missing data, and device error. In addition, we demonstrate how tracking device data can be integrated with accelerometer data to assess where physical activity takes place over the normal daily routine.

Methods

Subjects

The study protocol was reviewed and approved by the Johns Hopkins Institutional Review Board and all subjects signed written informed consent.

Subjects were recruited locally through advertisements and word of mouth. Participants were 35 men and women aged 18 years or older who were willing to wear the study devices for 1 week and reported good cell phone reception at home. Individuals anticipating plane travel during the study week were excluded. Participants were compensated after completion of the study.

Subjects completed a baseline evaluation to gather demographic information and anthropomorphic measurements, after which they were given devices to measure their physical activity and location.

Measurement of Travel and Physical Activity

Travel was evaluated through a tracking device (pTrac Pro, Brickhouse Securities, New York) and a self-reported travel log. The tracking device has no other functions found in a phone, and uses the Sprint cellular network to provide location information. Access to the network requires monthly fees (paid for by the investigators). While the device can theoretically use GPS signals as well, all device locations provided over 2 weeks of pilot testing were obtained through the cellular network, even though no attempt was made to deactivate the GPS capabilities of the device during either the pilot testing or study.

Tracking devices were set to obtain location at 15-minute intervals between 7 AM and 11 PM to maximize battery life, though the device allows location sampling as frequently as every 5 minutes. The device, without user programming, automatically follows up unsuccessful location attempts with additional location attempts at 5-minute intervals until a location is successfully obtained. Additional location attempts are also made after a change in location following many locates obtained at the same area (ie, during travel to work after being at home during the morning). The decision to obtain these additional locations is made by the device, and cannot be programmed or modified by the user.

Subjects were asked to carry the travel log with them (Figure 1) and to record travel which they estimated to be more than one-third of a mile away from home. For each journey, subjects recorded the time they left and returned home, and each destination where they stopped for at least 5 minutes. For each destination, subjects were asked to provide an address, or information sufficient to obtain the address. Information on the mode of travel (foot, car, train, etc.) was not obtained.

Finally, subjects were given an accelerometer (Actical, Respironics Inc.) to measure their physical activity over the study period. Accelerometers were set to record activity and steps in 1-minute epochs over the full study period. The activity level for each minute was assigned using the cut points described by Colley et al,²⁹ with counts/minute greater than 1535 defined as a minute of moderate-to-vigorous physical activity (MVPA).

Subjects were instructed to clip both the tracking device and accelerometer to their right waistband during all waking hours for 1 week except while showering or in water. Subjects were queried to determine a time they would be certain to be awake on both weekdays and weekends (most often between 7–9 AM), and live calls from a research staff member were made to subjects at these times reminding them to wear the 2 study devices and to complete the travel log. Subjects started and completed the study on a Wednesday.

Log/Device Reconciliation

Travel logs and study devices were returned 7 days after they were issued. Data from the tracking device included latitudes and longitudes at all time points for which the subject was successfully located. The home location and the location of destinations away from home were determined using ArcGIS Explorer.³⁰

Subjects were classified as being in the home region if their location was found to be within 536 m (1/3 mile) of the home location, and away from home if they were more than 536 m

away from this location. The distance of 536 m was chosen based on preliminary data in which the device reported accuracies ranging from 12–536 m for locations provided at different time points. Periods spent in or away from the home region were then defined as described in Figure 2. Unsuccessful locates, defined as failures of the tracking device to determine a location, were not included when identifying home and away periods.

Statistical Analysis

Temperature and precipitation information was obtained for the 21287 zip code (corresponding to Johns Hopkins) at www.weather-warehouse.com. Battery termination was defined by the time of the last successful locate up until the Wednesday 9 AM point marking the end of the study period.

To determine the spatial precision of the tracking device, locations provided by the tracking device were compared with the ArcGIS-provided home location during periods of time the subject was known to be at home. These periods of known home time occurred before the first accelerometer activity noted for the day or after the last accelerometer activity of the day, during times when subjects' travel logs described them being at home. Device accuracy in identifying logged travel destinations was determined by calculating the minimum distance between logged destinations and locates from the corresponding person-day. Success was defined by a minimum distance of less than 536 m (1/3 mile), with the time of the minimum-distance locate occurring during the corresponding excursion.

Defining Time and Physical Activity In and Away From the Home Region.—

Time spent in and away from the home region was evaluated for the hours between 7 AM and 11 PM on days in which the tracking device battery was functional for the full day. Time between 2 consecutive tracking device–provided locations falling within the home region was defined as home time, while time between 2 consecutive locations away from home region was defined as away time. Compliance with the study devices was inferred from accelerometer compliance, and days showing less than 8 hours of time between the first and last accelerometer readings were excluded.

Accelerometer data for minutes within home periods were used to quantify physical activity performed in the home region, while accelerometer data for minutes falling within away periods were used to quantify activity away from home. Data falling in between home and away periods were excluded because it was unclear whether the individual was within or away from home area. In analyses describing activity normalized over time (ie, steps/minute or percent of time spent in MVPA), the time between 7 AM and the first recorded count, or between 11 PM and the last recorded count, were excluded as subjects were likely sleeping or not wearing the device.

A preliminary data review demonstrated that the tracking device would occasionally locate subjects away from home region during a time they were in the home region, or (less frequently) place them in the home region during a time they were away from home. These errors resulted in an artificially high number of home and away time periods, though in nearly all instances only a single erroneous location was the source of the problem. Therefore, algorithms eliminating home or away periods defined by a single tracking

device–provided location were tested for their ability to yield more accurate results, using the travel log as a gold standard.

All analysis was performed using STATA 10 (College Station, Texas). Variables and regression model residuals were evaluated for normality using the Shapiro-Wilks test. Significance of differences between normally-distributed variables was determined using Students' *t* test, using the assumption of unequal variances, while differences between nonnormally distributed variables were determined using the Wilcoxon rank-sum test.

Results

Study Population

Thirty-five patients were enrolled in the study and all completed the study procedures. Participants had a mean age of 38 years (range 18–61 years), and all lived in Baltimore city or the surrounding suburbs. Seventy-four percent of participants were women and 29% were African American. Fourteen subjects (40%) were over-weight (BMI between 25 and 30), while 8 (23%) were obese (BMI ≥ 30). All subjects were enrolled between January and April 2009, when the average daily high temperature was 50°F.

Evaluation of Tracking-Device Function

Median battery life for the tracking device was 92.3 hours, corresponding to 5.8 study days. All batteries lasted at least 68 hours (over 4 full study days), while 22% lasted the full study period (102 study hours). Prolonged time between successful locates was uncommon, with 96.7% of study time points found within 15 minutes of a successfully provided location. Most study time also (95.7%) fell into definable home and away periods.

Compliance and Device Accuracy

Estimated accelerometer wear time spanned at least 8 hours in 96.4% of person-days, and both accelerometer and tracking device data were excluded for person-days not meeting this criterion.

Spatial accuracy of the tracking device was estimated by comparing the tracking device–provided location and the home location during time the subject was known to be at home. The location provided by the tracking device was within 325 m of the location derived from the home address 99.6% of the time, and within 100 m 79.6% of the time. For logged destinations away from home, subjects were found within 1/3 mile (536 m) of the destination location 83.6% of the time.

The tracking device correctly identified 848 out of 860 (98.6%) time periods away from home. Eighty-three erroneous time periods away from home were also noted by the tracking device, and such errors were more common in people leaving their home region more frequently (Figure 3). Eliminating home and away periods defined by a single tracking device location corrected 72 of these erroneous time periods (86.8%), and only slightly increased (from 1.4%–2.5%) the percentage of logged excursions away from home which were missed by the device (Figure 3a and 3b). Therefore, this filtering algorithm was employed in all subsequent analyses examining the number of time periods spent away from

home. The travel log and the locating device detected similar amounts of time spent away from home independent of whether the filtering algorithm was used (Figures 3c and 3d).

Features of Out-of-Home Travel

The mean number of distinct daily periods spent in or away from the home region was 4.2 periods/day (range 2.4–6.9, SD 1.1), and did not vary with age, race, gender, body-mass index, home zip code population density, and or daily precipitation. Time spent away from home did not significantly differ across weekdays ($P > .05$ for all pairwise comparisons), though subjects spent less time away from home on weekends as compared with week-days ($P < .001$; Figure 4).

Physical Activity In and Away From the Home Region

The majority of walking was performed away from home on weekdays, with median of 4255 steps/day taken away from home [Interquartile range (IQR) = 2921–6444] as compared with a median of 848 steps/day taken in the home region (IQR = 433–1801; $P < .001$). For weekends, no significant differences were seen in the number of steps taken in the home region (median of 1741, IQR = 530–3163) as compared with away from home (median of 2150, IQR = 1252–2851; $P = .29$). The large majority of weekday MVPA also took place away from home [median of 19 MVPA minutes away from home (IQR = 9–31 minutes) vs. a median of 0 minutes in home region (IQR = 0–2 minutes), $P < .001$]. More MVPA also took place away from home on weekend days [median of 5 minutes away from home (IQR = 2–10 minutes) vs. 1 minute (IQR = 0–4 minutes) in the home region, $P = .01$].

Activity measures were calculated again after adjusting for the amount of time spent in and away from the home region (Table 1). During weekdays, the median subject walked 7.4 steps per away minute (IQR = 5.4–10.0) as compared with 4.9 steps per home minute (IQR = 2.9–7.9; $P = .004$). This persisted for weekend days, with subjects walking 8.6 steps per away minute (IQR = 5.5–12.5) vs. 4.3 steps per home minute (IQR = 2.0–7.2; $P < .001$). A greater percentage of weekday time was also spent in MVPA during periods away from home (median = 3.5%, IQR = 1.9%–4.6%) as compared with time spent in the home region (median = 0.0%, IQR = 0.0%–0.7%; $P < .001$). Likewise, a greater percentage of weekend time away from home was spent in MVPA (median = 1.7%, IQR = 0.7%–3.5%) as compared with weekend time spent in the home region (median = 0.3%, IQR = 0.0%–0.9%; $P = .003$).

Differences in home and away activity measures were found consistently for individuals with varying activity levels (as defined by the total number of daily steps taken; Table 1). Neither time away from home nor the number of distinct trips away from home was predictive of the amount of walking or MVPA performed, either over the full study period or for any individual day of the week ($P > .05$ for all).

Discussion

The current study was designed with 2 purposes in mind: to investigate whether cellular network-based tracking devices could accurately identify time spent away from home, and to study whether a sample of working-age adults was more physically active away from

home. We found that the cellular network–based tracking device was accurate in measuring time spent away from home and quantifying excursions away from home. We also demonstrated how these devices could be combined with accelerometers to identify where physical activity takes place. Using these methods, we found that a small sample of working-age adults was more physically active when away from home.

Cellular network–based tracking devices have a role in quantifying and measuring physical activity away from home. The earliest studies looking at travel away from home employed life space questionnaires.^{31–33} These questionnaires are easy to use and, unlike our device, can provide some estimate of travel to locations just outside the house, such as a porch, yard or garden. However, they are subjective and require accurate subject recall which may not be possible in certain populations (ie, children, the elderly, or the ill). Traditional life space questionnaires provide limited information regarding when people leave their home or details regarding where they go, and a travel log did serve as the gold standard in our study. However, the log was a burdensome task for both the subjects (lots of effort and potential privacy issues) and the investigators (need to determine and geocode the address of all destinations, often after discussions with the subjects). The time-stamp and location provided by our tracking device allowed us to very simply analyze travel away from home by day of the week, integrate time-stamped information from an accelerometer, and accurately identify the large majority of destinations to which subjects traveled.

We also see specific areas where the tracking device used here would be preferable over GPS-based tracking devices. GPS cannot track individuals well indoors, typically leading to large periods of missing location data. Indeed, most studies combining GPS and accelerometer data have focused primarily on outdoor activity,^{15,16,18,22} though recent work has also revealed substantial difficulties of some GPS trackers in mapping outdoor travel.¹⁷ The few studies which combined accelerometer and GPS data over the full course of daily activities were only able to merge 30–60% of time points.^{18,20,25} Additionally, most GPS units require daily recharging, making compliance a possible issue. Our cellular network–based tracking device rarely demonstrated prolonged drop-out periods, and consistently provided 4 days worth of location information on a fully charged battery. However, the device was substantially less spatially accurate than GPS (250 vs. 2 m), and is designed to provide location information at a much lower frequency than GPS devices (every 5–15 minutes vs. every 3–5 seconds). Therefore, we see advantages in using our tracking device when infrequent temporal sampling and relatively imprecise location information is acceptable, but data over the full course of daily activity is important. The endpoints used in this study demonstrate relevant health outcomes which meet this description, including how often people leave their home region, how much time they spend away from home, and how much physical activity is performed away from home.

Few studies have looked at where physical activity takes place over the full course of daily activity. One study in adults asked subjects to wear an accelerometer at all times, and a backpack-housed GPS tracker requiring daily charging when outside. The authors found that adults completed roughly 20% of their MVPA within 1 km of their home, with less MVPA noted within 1 km of work.²¹ Studies in children have found that greater time spent outside is associated with greater time in MVPA. These studies determined time spent outside either

through self-report, or by requiring the children to turn on a wrist-based GPS tracker whenever they left the home.^{34,35} In this study, we were able to distinguish time spent at home or close to the home from time spent away from home using a constantly-worn device which did not have to be recharged or turned on.

Our study focused on a convenience sample of working adults, limiting the generalizability of our findings. Nonetheless, our work illustrates how cellular network-based location data and accelerometer data can be combined, and we describe findings that can be explored through further study. Our subjects were more active away from home, though the amount of time spent away from home area did not predict how much physical activity was performed. Instead, individuals across the spectrum of physical activity were more active away from home, and the most active individuals were more active both in the home region and away from home when compared with less physically active individuals. As subjects performing the least amount of physical activity were still more active away from home, it is possible that interventions designed to increase the amount of time spent away from home could succeed in increasing daily activity.

Several other limitations should be noted regarding the technology described. The limited spatial accuracy of our tracking device limited our ability to distinguish whether activity took place in the home, or just away from home, such as in a yard or the local neighborhood where children might play. The decision to sample location every 15 minutes also led to a long battery life, but created periods of time in between defined home and away periods (4% of total study time) which had to be excluded. Increasing the frequency of location sampling to every 5 minutes (the most allowed by the device) might yield a more precise patterning of physical activity and travel and lead to fewer missed destinations, but would still be insufficient to map the routes taken for many commutes. In addition, compliance with the tracking device could not be directly measured, though good accelerometer compliance and the excellent agreement of logged and tracking device-calculated time away from home were reassuring. Finally, it is possible that the cellular network-based tracking device would function differently in other geographic locations.

Being able to travel away from home is clearly important to independent living and social well-being.¹³ Limitation of travel away from home has been associated with consequences to the health and well-being of the elderly,¹⁴ but its incorporation as a health outcome measure has been limited by the lack of objective ways to quantify travel away from home. Here, we demonstrate an effective method for quantifying travel away from home and integrating this information with measures of physical activities. Additional work in adult populations is required to confirm our finding that greater physical activity is performed in time spent away from home.

Acknowledgments

We would like to acknowledge Dr. Harry A. Quigley of the Wilmer Eye Institute for his critical comments on the manuscript. This work was supported by the Dennis W. Jahnigen Memorial Award, and by National Eye Institute grants K12 EY015025 and K23 EY018595.

References

1. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ*. 2006;174(6):801–809. 10.1503/cmaj.051351 [PubMed: 16534088]
2. Lynch BM, Cerin E, Owen N, Hawkes AL, Aitken JF. Prospective relationships of physical activity with quality of life among colorectal cancer survivors. *J Clin Oncol*. 2008;26(27):4480–4487. 10.1200/JCO.2007.15.7917 [PubMed: 18802160]
3. Leon AS, Connett J, Jacobs DR, Jr, Rauramaa R. Leisure-time physical activity levels and risk of coronary heart disease and death. The Multiple Risk Factor Intervention Trial. *JAMA*. 1987;258(17):2388–2395. 10.1001/jama.1987.03400170074026 [PubMed: 3669210]
4. Helmrich SP, Ragland DR, Leung RW, Paffenbarger RS, Jr. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *N Engl J Med*. 1991;325(3):147–152. 10.1056/NEJM199107183250302 [PubMed: 2052059]
5. Cummings SR, Kelsey JL, Nevitt MC, O'Dowd KJ. Epidemiology of osteoporosis and osteoporotic fractures. *Epidemiol Rev*. 1985;7:178–208. PubMed [PubMed: 3902494]
6. Paffenbarger RS, Jr, Hyde RT, Wing AL, Hsieh CC. Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med*. 1986;314(10):605–613. 10.1056/NEJM198603063141003 [PubMed: 3945246]
7. Kaplan GA, Seeman TE, Cohen RD, Knudsen LP, Guralnik J. Mortality among the elderly in the Alameda County Study: behavioral and demographic risk factors. *Am J Public Health*. 1987;77(3):307–312. 10.2105/AJPH.77.3.307 [PubMed: 3812836]
8. Grand A, Grosclaude P, Bocquet H, Pous J, Albarede JL. Disability, psychosocial factors and mortality among the elderly in a rural French population. *J Clin Epidemiol*. 1990;43(8):773–782. 10.1016/0895-4356(90)90237-J [PubMed: 2143526]
9. Rakowski W, Mor V. The association of physical activity with mortality among older adults in the Longitudinal Study of Aging (1984–1988). *J Gerontol*. 1992;47(4):M122–M129. PubMed [PubMed: 1624695]
10. Simonsick EM, Lafferty ME, Phillips CL, et al. Risk due to inactivity in physically capable older adults. *Am J Public Health*. 1993;83(10):1443–1450. 10.2105/AJPH.83.10.1443 [PubMed: 8214236]
11. Ruigomez A, Alonso J, Anto JM. Relationship of health behaviours to five-year mortality in an elderly cohort. *Age Ageing*. 1995;24(2):113–119. 10.1093/ageing/24.2.113 [PubMed: 7793332]
12. Bijnen FC, Caspersen CJ, Feskens EJ, Saris WH, Mosterd WL, Kromhout D. Physical activity and 10-year mortality from cardiovascular diseases and all causes: The Zutphen Elderly Study. *Arch Intern Med*. 1998;158(14):1499–1505. 10.1001/archinte.158.14.1499 [PubMed: 9679790]
13. Shimada H, Ishizaki T, Kato M, et al. How often and how far do frail elderly people need to go outdoors to maintain functional capacity? *Arch Gerontol Geriatr*. 2010;50(2):140–146. 10.1016/j.arch-ger.2009.02.015 [PubMed: 19356806]
14. Xue QL, Fried LP, Glass TA, Laffan A, Chaves PH. Life-space constriction, development of frailty, and the competing risk of mortality: the Women's Health And Aging Study I. *Am J Epidemiol*. 2008;167(2):240–248. 10.1093/aje/kwm270 [PubMed: 17906296]
15. Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. *Int J Behav Nutr Phys Act*. 2010;7:31 10.1186/1479-5868-7-31 [PubMed: 20412582]
16. Cooper AR, Page AS, Wheeler BW, et al. Mapping the walk to school using accelerometry combined with a global positioning system. *Am J Prev Med*. 2010;38(2):178–183. 10.1016/j.amepre.2009.10.036 [PubMed: 20117574]
17. Oliver M, Badland H, Mavoa S, Duncan MJ, Duncan S. Combining GPS, GIS, and accelerometry: methodological issues in the assessment of location and intensity of travel behaviors. *J Phys Act Health*. 2010;7(1):102–108. PubMed [PubMed: 20231761]
18. Quigg R, Gray A, Reeder AI, Holt A, Waters DL. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. *Prev Med*. 2010;50(5–6):235–240. 10.1016/j.ypmed.2010.02.002 [PubMed: 20153361]

19. Wheeler BW, Cooper AR, Page AS, Jago R. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. *Prev Med.* 2010;51(2):148–152. 10.1016/j.ypmed.2010.06.001 [PubMed: 20542493]
20. Rodriguez DA, Brown AL, Troped PJ. Portable global positioning units to complement accelerometry-based physical activity monitors. *Med Sci Sports Exerc.* 2005;37(11, Suppl):S572–S581. 10.1249/01.mss.0000185297.72328.ce
21. Troped PJ, Wilson JS, Matthews CE, Cromley EK, Melly SJ. The built environment and location-based physical activity. *Am J Prev Med.* 2010;38(4):429–438. 10.1016/j.amepre.2009.12.032 [PubMed: 20307812]
22. Troped PJ, Oliveira MS, Matthews CE, Cromley EK, Melly SJ, Craig BA. Prediction of activity mode with global positioning system and accelerometer data. *Med Sci Sports Exerc.* 2008;40(5):972–978. 10.1249/MSS.0b013e318164c407 [PubMed: 18408598]
23. Duncan MJ, Badland HM, Mummery WK. Applying GPS to enhance understanding of transport-related physical activity. *J Sci Med Sport.* 2009;12(5):549–56. PubMed [PubMed: 19237315]
24. Elgethun K, Fenske RA, Yost MG, Palcisko GJ. Time-location analysis for exposure assessment studies of children using a novel global positioning system instrument. *Environ Health Perspect.* 2003;111(1):115–122. 10.1289/ehp.5350 [PubMed: 12515689]
25. Phillips ML, Hall TA, Esmen NA, Lynch R, Johnson DL. Use of global positioning system technology to track subject's location during environmental exposure sampling. *J Expo Anal Environ Epidemiol.* 2001;11(3):207–215. 10.1038/sj.jea.7500161 [PubMed: 11477518]
26. Rainham D, Krewski D, McDowell I, Sawada M, Liekens B. Development of a wearable global positioning system for place and health research. *Int J Health Geogr.* 2008;7:59 10.1186/1476-072X-7-59 [PubMed: 19032783]
27. Wiehe SE, Carroll AE, Liu GC, et al. Using GPS-enabled cell phones to track the travel patterns of adolescents. *Int J Health Geogr.* 2008;7:22 10.1186/1476-072X-7-22 [PubMed: 18495025]
28. Wiehe SE, Hoch SC, Liu GC, Carroll AE, Wilson JS, Fortenberry JD. Adolescent travel patterns: pilot data indicating distance from home varies by time of day and day of week. *J Adolesc Health.* 2008;42(4):418–420. 10.1016/j.jadohealth.2007.09.018 [PubMed: 18346668]
29. Colley RC, Tremblay MS. Moderate and vigorous physical activity intensity cut-points for the Actical accelerometer. *J Sports Sci.* 2011;29(8):783–789. 10.1080/02640414.2011.557744 [PubMed: 21424979]
30. ESRI. ArcGIS Explorer. 2010.
31. Baker PS, Bodner EV, Allman RM. Measuring life-space mobility in community-dwelling older adults. *J Am Geriatr Soc.* 2003;51(11):1610–1614. 10.1046/j.1532-5415.2003.51512.x [PubMed: 14687391]
32. May D, Nayak US, Isaacs B. The life-space diary: a measure of mobility in old people at home. *Int Rehabil Med.* 1985;7(4):182–186. PubMed [PubMed: 4093250]
33. Stalvey BT, Owsley C, Sloane ME, Ball K. The Life Space Questionnaire: a measure of the extent of mobility of older adults. *J Appl Gerontol.* 1999;18:479–498. doi:10.1177/073346489901800404
34. Cleland V, Crawford D, Baur LA, Hume C, Timperio A, Salmon J. A prospective examination of children's time spent outdoors, objectively measured physical activity and overweight. *Int J Obes (Lond).* 2008;32(11):1685–1693. 10.1038/ijo.2008.171 [PubMed: 18852701]
35. Jones AP, Coombes EG, Griffin SJ, van Sluijs EM. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. *Int J Behav Nutr Phys Act.* 2009;6(1):42 10.1186/1479-5868-6-42 [PubMed: 19615073]

Date: 3-28-09

I left my home at 2:00pm time

I went to the following places (give address or cross streets):

1st Target - 5230 Campbell Blvd. Baltimore, MD 21236

2nd White Marsh Mall - 8200 Perry Hall Blvd.

3rd Baltimore, MD 21236

4th _____

5th _____

6th _____

I returned home at 4:30pm time

Figure 1 —.

Log of a sample excursion from a travel diary. Each excursion away from home was separately logged, including different excursions taken on the same day. Days for which no excursions were logged were confirmed with subjects at their end-of-study interview.

Figure 2 —.
Definition of home and away periods using tracking device data.

(a) Total home & away periods per day – unfiltered data, (b) total home & away periods per day – filtered data, (c) time away from home, unfiltered data, (d) time away from home, filtered data.

Figure 3 —.

Bland-Altman analysis comparing total home/away periods per day, or time away from home per day, calculated by the tracking device and travel log.

Boxes represents the interquartile range and line within box represents the median value. Outliers more 1.5 times the interquartile range away from the median value are shown as individual points.

Figure 4 —.
Time away from home by day of week.

Table 1
Median Levels of Activity Measures Among Subjects Performing Different Amounts of Walking

Activity measure	Full group	Tertile of average daily steps		
		Least activity	Intermediate activity	Most activity
Hours Away				
Weekdays	10.7 (8.9–11.3)	10.7 (8.1–11.1)	10.6 (8.9–11.5)	10.6 (9.5–12.0)
Weekends	5.1 (3.1–6.4)	5.0 (3.2–6.4)	5.5 (4.4–7.7)	4.7 (2.5–5.8)
Daily steps				
Weekdays	6704 (4497–8159)	4195 (2948–5070)	6739 (6314–7389)	9673 (7821–10,592)
Weekends	6099 (2193–7198)	2099 (1610–2928)	6430 (4929–6954)	7405 (5680–10,178)
Steps/minute, weekdays *				
Home	4.9 (2.9–7.9)	2.5 (1.7–3.8)	6.0 (5.2–8.0)	7.5 (3.7–13.5)
Away from home	7.4 (5.4–10.0)	5.8 (4.5–6.6)	8.5 (6.1–9.3)	10.0 (4.8–15.7)
Steps/minute, weekends *				
Home	4.4 (2.0–7.2)	1.4 (1.0–2.3)	5.7 (3.8–7.7)	7.2 (3.9–9.7)
Away from home	8.6 (5.5–12.5)	5.3 (2.9–8.6)	8.2 (5.7–11.3)	13.0 (11.0–20.3)
Total MVPA minutes				
Weekdays	21 (13–38)	12 (10–20)	27 (18–35)	32 (21–64)
Weekends	11 (3–16)	2 (2–6)	12 (9–14)	18 (14–38)
% time in MVPA, weekdays *				
Home	0.1 (0–0.7)	0 (0–0)	0.4 (0–1.9)	0.2 (0–0.9)
Away from home	3.5 (1.9–4.6)	2.3 (1.4–3.3)	4.0 (2.1–4.7)	4.1 (2.8–10.5)
% time in MVPA, weekends *				
Home	0.3 (0–0.9)	0 (0–0)	0.4 (0.3–1.7)	0.9 (0.2–1.8)
Away from home	1.7 (0.7–3.5)	1.1 (0.4–1.5)	1.8 (0.8–2.8)	4.1 (3.0–12.3)

Interquartile ranges shown in parentheses.

* Time in between home and away locates not included in analysis.