Neighbourhood for Playing: Using GPS, GIS and Accelerometry to Delineate Areas within which Youth are Physically Active

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Article

Neighbourhood for Playing: Using GPS, GIS and Accelerometry to Delineate Areas within which Youth are Physically Active

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Abstract

Despite the documented importance of the neighbourhood environment on youth physical activity, little empirical research exists regarding the geographical boundaries of neighbourhoods within which youth are physically active around their homes. Studies and public policies often arbitrarily assume the extent of these boundaries, which vary from study to study. This paper combines GPS data, diaries and accelerometry to delineate empirically the local area and distance within which youth play in Erie County, New York. The study found that youth tend to be physically active within a quarter-mile radius around their homes and to focus on one section of the often assumed circled neighbourhood.

Introduction

Concerns about rising rates of obesity and other related health problems have stimulated research and policy on promoting physical activity through modification of the built environment (Forsyth *et al*., 2008; Raja *et al*., 2010; Frank *et al*., 2003, 2006; Saelens *et al*., 2003; Sallis *et al*., 2004; Roemmich *et al*., 2006, 2007). Much of the research and policy effort, however, focuses on the experiences of the adult population despite significant and myriad reasons for retaining a focus on youth. The trajectory of obesity is often established during childhood (Bertheke Post *et al*., 2001; Whitaker *et al*., 1997). Moreover, studies have suggested that, compared with adults, physical activity among youth is more susceptible to influences of their neighbourhood environments (van Vliet, 1981; Wohlwill and van Vliet, 1985). Youth's experiences within

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and uses of the built environment are different from those of adults (Maas *et al.*, 2006; van den Berg *et al.*, 2010; van Vliet, 1981).Youth engage in different activities and they may also travel within a smaller range because they have fewer freedoms and reduced autonomy to use their built environment (Handy, 2005; Maas *et al.*, 2006). Nonetheless, youth do make choices between being physically active or sedentary, and their choices are influenced by the design of and access to play spaces within their neighbourhood built environment (Roemmich *et al.*, 2006, 2007; Sallis *et al.*, 1990; van Vliet, 1981). In order to develop effective policies to create neighbourhood environments that are responsive to youth's needs for physical activity, it is essential to understand how youth utilise their environments. This study contributes to this by analysing the spatial extent and distance that youth are physically active within the immediate neighbourhoods around their residences.

Studies and policies vary in how they define the extent of a neighbourhood and how to measure the features of these neighbourhoods. Some have used self-reported data from travel diaries or perceptual data from environmental audits and surveys to elicit information regarding participants' perceived or assumed neighbourhood environment (van Vliet, 1981; Fine, 1967). Others have used objective data from geographical information systems (GIS) or a combination of self-reported and GIS data to assess physical-activity-related neighbourhood environmental attributes (Frank *et al.* 2006; Frank *et al.*, 2004). Across these studies, the geographical boundaries of neighbourhoods are defined rather arbitrarily even though they are likely to vary by population sub-group (for example, adults versus youth or various sub-groups of youth) (van Vilet, 1983; Anderson and Tindall, 1972; Coates and Bussard, 1974). Some studies have used a half-mile radius around adolescents' residences to define neighbourhoods of children and youth (Roemmich *et al.*, 2006, 2007). Other studies have used a one-mile radius, five-minute walking areas or census boundaries to define neighbourhoods (Raja *et al.*, 2010; Frank *et al.*, 2006; Cervero and Duncan, 2003; Krizek and Johnson, 2006; Spokane *et al.*, 2007).

However, there is little empirical basis to support these neighbourhood definitions, which may undermine the measurements of youth's neighbourhood environments and lead to erroneous estimation about the contribution of neighbourhood environment characteristics to youth physical activity by excluding or including neighbourhood attributes that youth do or do not use or experience. The use of different neighbourhood definitions that were arbitrarily assumed may make studies that have examined associations between the built environment and physical activity incomparable, controversial and problematic (Lathey *et al.*, 2009).

The spaces that youth utilise for physical activity are often shaped by the design of their neighbourhood built environment. A survey of 148 high school students found that the mean distance travelled from their homes for selected activities ranged from 420 metres to 5940 metres (van Vliet, 1983). Although it is possible to increase spatial reach of youth to access distant built environment features that facilitate physical activities by developing public transport responding to their mobility needs, it is important to make these features available in close proximity to where youth live in their local immediate neighbourhoods (van Vliet, 1983). Little empirical research has determined the distance and area of local immediate neighbourhoods within which youth play, walk, and bicycle from their homes.

This paper contributes to the literature by empirically documenting and studying the spatial extent of the neighbourhood within which youth obtain physical activity through playing, walking and bicycling near their homes. This work extends planners' understanding of the relationship between the built environment and youth's physical activity to help to improve the designing and planning of neighbourhood environment for youth. This study integrates both subjective and objective data on the time, location and intensity of physical activity of adolescents. It combines self-reported diaries and objectively measured activity data on active play to supplement global positioning system (GPS) data to help to delineate the distance and area of youth's play areas in their immediate vicinity, and to examine the variability across youth in the size of these neighbourhoods. The findings provide important information for setting empirically grounded boundaries of youth's active play areas when assessing the associations of built environment attributes on youth's physical activity. The problems and limitations related to the implementation of GPS data collection, data quality and the reliability of GPS measurements are also discussed.

Linking Subjective and Objective Data to Assess the Activity-enabling Environment

To understand how the varying features of the built environment constrain or facilitate physical activity among youth, researchers need two types of data: one on the built environment and the other on physical activity. Commonly used subjective data collection methods that help to measure built environment and physical activity include the use of travel diaries, surveys and environmental audits. Self-reported data on location, time and intensity of activity in the forms of survey or diary provide information regarding neighbourhood environment attributes experienced by youth, but may be unreliable because subjects may recall wrong locations or inaccurate times and types of activities (Robinson and Godbey, 1997, pp. 57–67; Phillips *et al*., 2001; Lathey *et al*., 2009). Recent technological advances allow researchers to collect, analyse and integrate objective and subjective micro-level data on location, time and intensity of activity. In what follows, we describe the methodological processes and potentials for pursuing such integration.

GPS record positions as points that are linked to time-stamps as an individual plays, walks, bikes or drives outdoors. GPS technology provides relatively accurate data for locating position, determining direction, velocity and time of travel and these data can be easily incorporated into a GIS. GPS has been used to collect data for traffic analysis and to track the location of trucks for many years (Quiroga and Bullock, 1998; D'Este *et al*., 1999).

The improvements made in the portability, affordability and accuracy of GPS units have been increasingly attracting researchers to use GPS for studying individual travel behaviour (Grengs *et al*., 2008; Zhu, 2003). GPS can be used to estimate travel speed of walking, running and bicycling (Schutz and Chambaz, 1997). Grengs *et al*. (2008) suggested that planners can benefit from the use of GPS data for travel studies because they can help to capture detailed spatial and temporal information regarding movement throughout the full trip.

Thus, GPS holds benefits for the study of environment determinants of youth physical activity behaviour. It allows for the collection of individual-level data on the use of the neighbourhoods where youth play, walk and bike. The spatial location and time information can be used to derive various parameters potentially useful for studying the link between the built environment and the physical activities of adolescents. For example, the position and time information can be used to determine an individual's travel speed and travel mode. More importantly, detailed space–time trajectories at the individual level can help to define the spaces used most frequently by youth for playing and the farthest distance youth are willing to walk or bike within their neighbourhoods.

Objectively collected time and location information from GPS can be cross-referenced and verified with a self-reported travel diary when the self-reported data are plotted using GIS data and GIS's spatial and visualisation functionalities. Travel diaries provide valuable information for cross-referencing and verifying GPS data because youth may forget to wear the GPS unit or the units may not be able to collect data due to interference caused by tall buildings or dense overhead foliage. Based on parcel, street and orthoimagery data, GPS points can be translated into streets and house numbers, and diary data collected can be translated and mapped to points for these two datasets to be compared and matched for data validation and verification purposes.

Information on where and when youth play in their immediate vicinity collected using GPS can be linked to the intensity of their physical activity with the help of an accelerometer. Accelerometers provide information regarding the amount and intensity of movement of the body. Accelerometers provide an objective means of measuring the intensity, duration and overall amount of physical activity by youth and adults (Schmitz *et al*., 2005; Larsen *et al*., 2009). Although accelerometers offer objective data on intensity of physical activity, they do not offer spatial information about the location of physical activity.

Accelerometer data, GPS data and travel diaries can be linked to help to integrate objectively and subjectively collected information on location, time and activity, and to identify places where youth play, walk and bicycle. To delineate youth's play neighbourhood, the data collected using GPS and travel diary as individual points or locations need to be converted to polygons or areas. A convex hull is the smallest convex polygon that surrounds a set of points (Graham, 1972). It shows the boundary of the minimal convex that contains a given finite set of points in a plane. The most popular algorithms for calculating a convex hull are the Graham scan algorithm (Graham, 1972) and the divide-and-conquer algorithm (Preparata and Hong, 1977). Convex hulls have had many applications including pattern recognition, hidden object determination and shape analysis (Akl and Toussaint, 1978; Paulos, 1998). Utilising a combination of GPS, travel diary and accelerometer data, convex hulls can help to delineate the boundaries of a youth's neighbourhood—i.e. the smallest boundary surrounding all of the points where youth play, walk and bicycle. We demonstrate the utility of this convex hull in the following case study of youth in Erie County, New York.

Research Design and Method

The section demonstrates the use of the methodological advances described earlier on the integration of multiple sources of data to document the spatial extent of neighbourhoods within which youth choose to play, walk or bicycle around their homes.

Data Collection

Secondary data collected included parcel data from Erie County Assessor's Office, street data and ortho-imagery obtained from New York State GIS Clearinghouse. Primary data were collected using GPS units, accelerometers and travel diaries. The study sample comprised of 20 boys and 20 girls, aged between 10 and 15 years, randomly recruited from Erie County, New York, US. This age-group includes the developmental period of adolescence that is a critical period for a reduction in physical activity and obesity (Epstein *et al.*, 2001). All subjects were non-obese. Only non-overweight and overweight youth were included in the study to reduce variability because obese youth differ in physical activity motivation and behaviour.

For one week, participating youth wore a portable Garmin Fortrex GPS unit around their wrist to record their outdoor location. Concurrently, youth wore a pager-sized accelerometer (Biotrainer, Santa Monica, CA) at the waist and superior to the hip to collect objective measures of physical activity intensity for one week. The display on the accelerometer was turned off so that participants did not receive any feedback regarding their physical activity level. Youth were also asked to document the locations, time and activities for the same week using a travel diary with one-hour intervals. After the completion of the one-week study period, the GPS and accelerometer data were downloaded to a computer and the travel diary was reviewed with a parent to fill-in any missing data and answer questions about ambiguous travel behaviour entries.

Integrating GPS, Travel Diary and Accelerometry Data

The GPS, travel diary and accelerometry data were processed and imported into ArcGIS to build an integrated database. The data were cross-referenced and verified to obtain the location, time, intensity and type of physical activity of subjects over the one-week period. The database also included a range of GIS datasets such as street centre-line, parcel and orthophotos.

The GPS data contained information on subjects' ID number, sex, x and y co-ordinates of each GPS data point, and time and date that each point was recorded. Based on this information, the tracks of each participant's travel trajectories were mapped using ArcGIS. GPS data collection allowed for both static and dynamic recordings of youth's positions over time.

The next step involved linking the accelerometer and GPS data, and verifying the GPS data against the travel diaries. Accelerometer and GPS data share a common attribute of time, which allowed linking these two datasets. The accelerometer data includes the subjects' ID number, physical activity level transformed into metabolic equivalents (METs) and the time and date. Both accelerometer and GPS data were processed to create two new files with one point, or one record, per minute so that every row or record in the accelerometer data could be matched with every record in the GPS data. A new point GIS file was created using records that contain information from GPS and accelerometry.

To verify information in the GPS data with the travel diaries, GPS tracks were overlaid with the parcel and street map and orthophotos to identify locations and compare with the locations and times recorded in the diaries. Some GPS points did not match travel diaries. In these cases, accelerometer data were compared with GPS and diary data to determine if any two datasets matched. Data points were coded as missing and discarded if the data could not be verified as being correct.

Participants' Neighbourhood Built Environment

The participants come from neighbourhoods across Erie County, New York, that offer significant variation in built form and typology. Before trying to delineate neighbourhood sizes within which youth play around their residence, various built environment variables and statistics were calculated for the sampled participants' neighbourhoods and for the whole county. Note that this was done to get information on the sampled neighbourhoods and their relation to the county average and variation so that the delineation of the neighbourhood boundaries generalised based on the sample from this study do not represent only a singular type of neighbourhood.

Several built environment variables were calculated to help to assess characteristics of the sampled neighbourhood environment following Frank *et al.* (2006), Raja *et al.* (2010), and Roemmich *et al.* (2006, 2007). These variables were calculated based on the widely used one-half-mile network-distance neighbourhoods around participants' residences, to be comparable with many precedent studies. They include street length, housing density, percentage of the area used for physically active recreation, percentage of park and recreational land, average block size and percentage of residential land. These variables were also calculated for all the residential parcels in the county by drawing a one-half-mile boundary around each residential parcel. Since there are more than a quarter of a million residential parcels in the county, one out of every four adjacent parcels was selected for the calculation.

Establishing Neighbourhood Boundaries Using Convex Hulls

Only non-automobile travel which originated from a participant's residence or an extension of non-automobile trips that originated from a participant's residence, were included in defining youth's play neighbourhoods. In other words, if a participant was driven to a location one mile away from home and then walked from that location to start a non-automobile trip, the points for that trip were not included in the analyses.

GPS tracks with non-automobile travel modes around each participant's residence were identified based on travel speed. Travel speed was calculated using the distance between two adjacent points divided by the time difference between them. Literature suggests that the average walking speed is three to four miles per hour and the average biking speed is about ten miles per hour (Pate *et al.*, 1995). The points with a speed less than three and half mile per hour were coded "walking or playing" and the points with a speed less than nine miles per hour and greater than three miles per hour were coded "biking or running". The present study focused on the area within a four-mile radius around the youth's homes because no playing points were found outside the four-mile area.

Convex hulls were calculated and drawn to include all active playing points to establish each participant's actual playing area around their residence in ArcGIS. Each convex hull covers all GPS points that were identified as active playing in one day for a participant. These convex hulls illustrated which area in a participant's neighbourhood that the participant used for playing, walking, biking and running, or in which part of the neighbourhood they played.

To summarise how the playing points were distributed or play neighbourhoods were shaped for all participants, the convex hulls were overlapped to show the active play neighbourhood around participants' residences. Participants' residences were used as the reference points for moving all subjects' convex hulls together and for overlapping them. This was done by grouping and attaching all convex hulls for a participant to his/her residence. After overlapping, all participants' homes were laid on top of each other and displayed as a single point in ArcGIS.

To quantify the intensity or frequency of an area being used or visited by youth, the convex hulls were converted to ArcGIS raster files. All converted raster files have the same map extent and cell size of 20 by 20 feet. Cell statistics were calculated for every cell regarding how many times the cell was visited by youth based on the convex hulls. Note that cells covered by the convex hulls are the cells that fall within polygons that represent theoretical zones of play activity, although some of them may not actually be visited. The distance of each cell to home was also calculated. The information on every cell's distance to home and its frequency of being visited by youth helped to delineate youth's play neighbourhood around their homes.

Consecutive rings with increments of a one-half-mile radius to a total of four miles were drawn around youth's homes and overlaid on top of the visit frequency map to demonstrate and identify how frequency of visiting a cell changed as distance from home increased. To further investigate the relationship between the frequency of an area being used for active play and its distance to home, the area within the half-mile ring around youth's homes was selected as the focus area. More rings were drawn within the half-mile ring—one ring for every one-tenth mile from youth's homes.

The values of frequency of visits to a cell were standardised and converted into a frequency index. The reason for standardisation is that cells with the same distance-to-home value may have different values of frequency of visits because youth may be playing in different sections of the circled neighbourhood. The frequency index was calculated to get the average number of visits during the one-week period that a cell was visited using the following formula

$$FI_{id} = \sum \{F_{id}\}/N_d$$

Where *FI* is the frequency index for the cells at the distance of *d* from home; *i* represents cell number *1* to *n* at distance *d*; *F* is the number of visits to cell number *i*; *N* represents number of cells at distance *d*.

The visit frequency index was plotted against the distance to home to depict and identify the relationship between visit frequency and distance to home within both the three-mile area and the one-half-mile focus areas. The areas visited by boys and girls were compared to determine whether there was any difference between the spatial extent of boys' and girls' play neighbourhoods, using the same method already outlined.

The physical activity literature suggests that metabolic equivalent (MET) intensities of three and greater are used to identify moderate to vigorous physical activity (Trost *et al.*, 2002; Roemmich *et al.*, 2006, 2007), which is the intensity of a brisk walk. The activity intensity in METs for every GPS point identified as walking or biking against the distance from each participant's residence was cross-tabulated and plotted. To help to identify the play neighbourhood, a line was drawn to mark walking or playing points with physical activity intensity above three METs in the charts. The three-MET line was not drawn for biking or running points because the accelerometer is not valid for bicycling exercise. During bicycling, the hip is supported by the seat and there is overall less movement than when walking, running or jumping and increases in intensity of pedalling are not detectable as the hip is stationary at the bicycle seat. Many types of active play are three METS or greater in intensity.

Findings and Discussion

Context: Participants' Neighbourhood Built Environment

Erie County, New York, offers a wide variety of environments for youth. Some youth

Table 1. Descriptive statistics for the participants' built environment (within network half-mile radius)

Built environment variables	*Maximum value*	*Minimum value*	*Mean*
Street length	226 348	16 325	101 903
Housing density	11.55	0.03	4.92
Percentage of land used for physically active recreation	79.61	38.49	62.10
Percentage of park land and recreational land	21.35	00.0	05.32
Percentage of residential land	81	13	50

participants were from the city of Buffalo while others were from inner-ring suburbs and exurban neighbourhoods. Table 1 reports the descriptive statistics for the sampled participants' built environment. The heterogeneity across the physical characteristics of these environments is evident in the variation in street design, land use mix, prevalence of parks and a variety of other features (Table 1). The street length in the sampled neighbourhoods ranges from 16 235 feet to 226 348 feet. The mean value is 101 903 feet or 19 miles. The percentage of park and recreational land ranges from 0 per cent to 21 per cent.

Figure 1 compares the built environment characteristics between the sampled neighbourhoods and the county average and variation. The dark dots represent values for each sampled neighbourhood. The thin black and thick grey lines represent sample mean and county mean respectively. Figure 1 illustrates that average block size, street length and park and recreation land ratio vary across the sampled neighbourhoods and the whole county. The mean street length in the sampled neighbourhoods is similar to the county mean. The mean percentage of park and recreational land of the participants in this study was 5 per cent, which is similar to the county mean, 4.97 per cent.

The heterogeneity within and between the sampled neighbourhoods ensures that the findings from this study are not the result of a singular type of neighbourhood. Figure 1 and Table 1 also provide important information about the geographical context of the study participants that will allow studies from other geographical areas to be compared with the present study. Note that the role played by individual neighbourhood characteristics in determining specific youth's neighbourhood boundary and shape is not the focus of this paper.

Neighbourhoods within which Youth are Physically Active

Figure 2 shows representative examples of youth's actively play neighbourhoods as convex hulls. The large black circle represents the subjects' residences; small black points are GPS tracks for playing, walking and biking; and the grey-shaded polygons are the convex hulls. The upper-left image shows an example of GPS points dropped in one day placed around one participant's residence. It also shows one convex hull that surrounds all of the walking and biking points on that day. This particular participant played in the area north-west and north of his/her residence on that day. The upper-right image shows all convex hulls created for that participant that cover all of the walking and biking points around this participant's residence for one week. This image illustrates that this participant

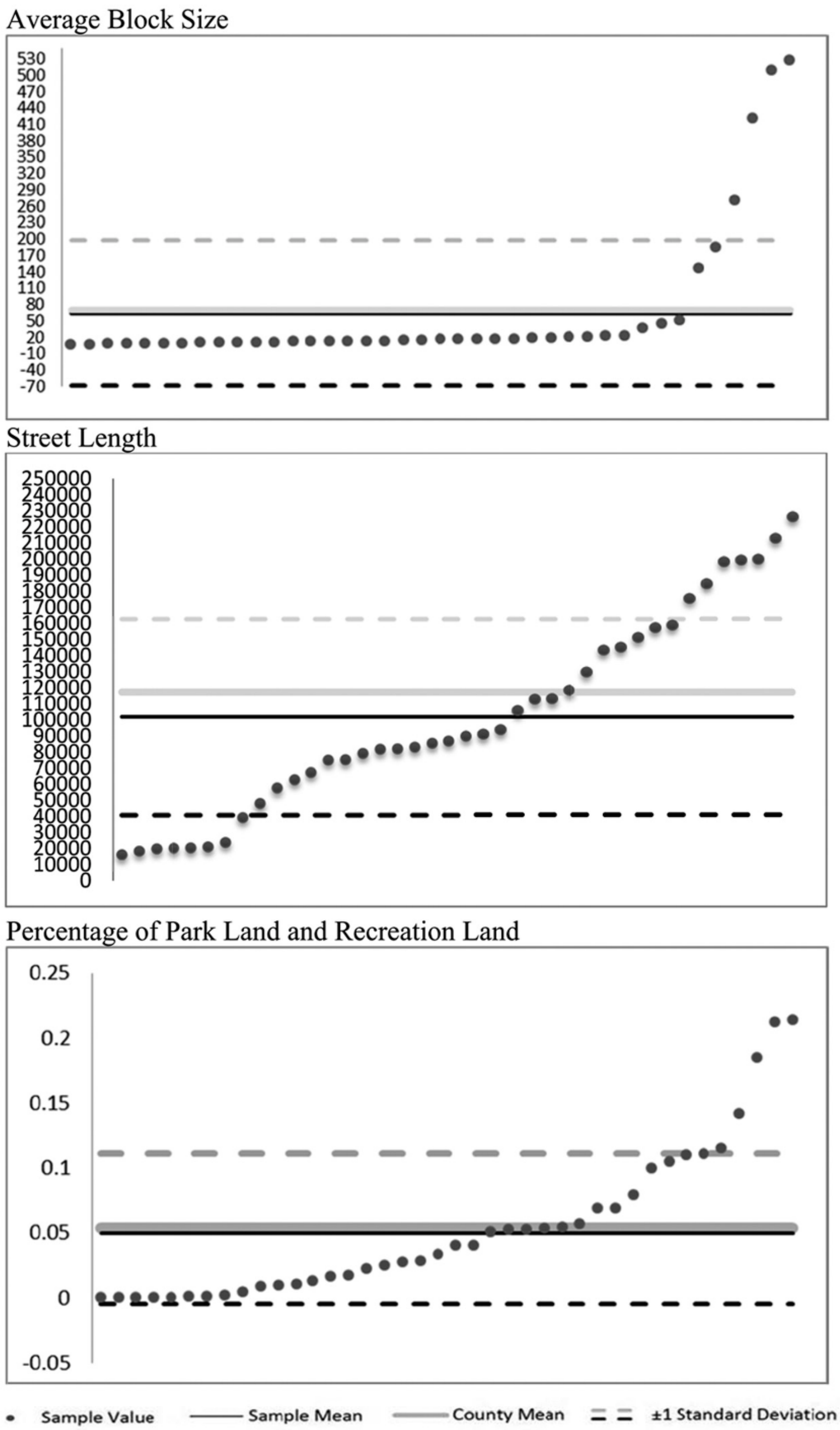

Figure 1. Built environment characteristics: sampled neighbourhoods vs county average (within half-mile radius).

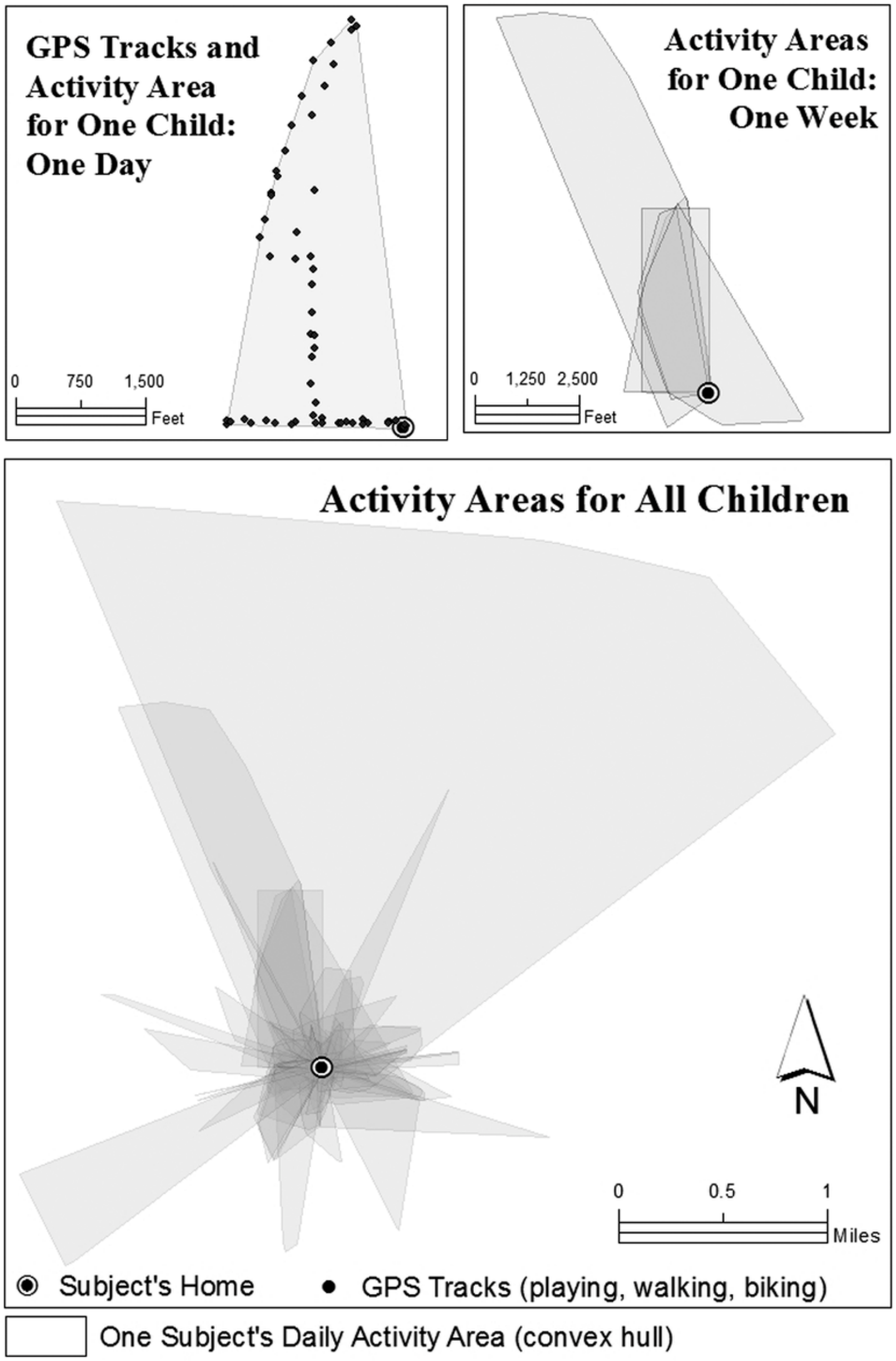

Figure 2. Youth's actively play neighbourhoods as convex hulls.

occasionally travelled and played further in the north-western direction, but most of the time played in the area closer to home, in the north-west direction. The image illustrates that, unlike what has been assumed by many studies, youth are not using the elements in the built environment around their homes equally in all directions.

The bottom image of Figure 2 shows the overlapped convex hulls generated for all of the participants in the study for the one-week period. Darker grey shading depicts a greater concentration of convex hulls and, therefore, a greater frequency of the areas being visited by the studied youth. There is a high concentration of convex hulls clustered in close vicinity to youth's residences representing areas being visited more frequently by these participants.

The bottom image also illustrates that one particular participant on one day went to an area far north-east, approximately three miles from home, and another went in a south-westerly direction. Some participants played in the area north-east of their homes; some in the south-west; and others in the south-east or other directions. The images in Figure 2 suggest that youth focus on one direction of the circled neighbourhood, yet often built environment attributes within the entire circled neighbourhood are used to determine the association of the built environment with the physical activity or adiposity of children, youth and adults. Using circled neighbourhoods and calculating built environment variables based on these circled neighbourhoods as done in many previous studies may have overestimated and misrepresented the neighbourhood environment characteristics and their contribution to the physical activity level by including neighbourhood attributes that youth do not use or experience.

Figure 3 shows distance and frequency of visits to the areas around participants' homes in three sets of images in three rows. The first row shows information on frequency of visits up to 4 miles; the second and the third focus on the areas within one-half mile; and the third row compares between boys and girls. Frequency of visits and distance to home are calculated and plotted at the scale of a cell, sized 20 by 20 feet. The images on the left are essentially the same as the bottom image of Figure 2; except that these images include cell statistics on visit frequency. The darker the cell's colour, the more frequently it was visited by the study subjects.

In the first row, the concentric rings overlaid on top of the frequency image on the left are placed at half-mile intervals, starting with the one-half-mile ring. The rings on the left are linked to the image on the right side. The graph on the right provides the frequency index on the *y* axis and distance to home on the *x* axis for each cell. The left image shows that the majority of the convex hulls fall inside the half-mile ring. The curve in the right panel shows that the average numbers of visits by a participant to the cells at different distances from home range between zero to almost six during the one-week period. The frequency drops quickly between zero and the three-tenths-mile distance range. Between three-tenths-mile and half-mile from youth's home, the frequency drops more slowly. After one-half mile, the frequency index drops under 0.5 and tends to be steadily close to zero. In other words, the average numbers of visits to the cells at one-half mile were a little less than 0.5, or only about half of the cells at the distance of one-half mile from home were visited once by youth in one week. The frequency index approached zero after one mile, which means that the cells in this distance range were almost never visited by the studied youth.

The images on the second row offer a more fine-grained view of the areas within the half-mile ring. In the left panel, five rings were plotted with one-tenth-mile intervals starting at the one-tenth-mile ring on top of the frequency image. There was a high frequency of visits within the one-tenth and two-tenths-mile rings. The right panel plots the relationship between frequency index and distance to home at this fine scale. Both images showed that, after the three-tenths-mile ring, the frequency index dropped to under one and approaches zero. In other words, the cells within the three-tenths-mile

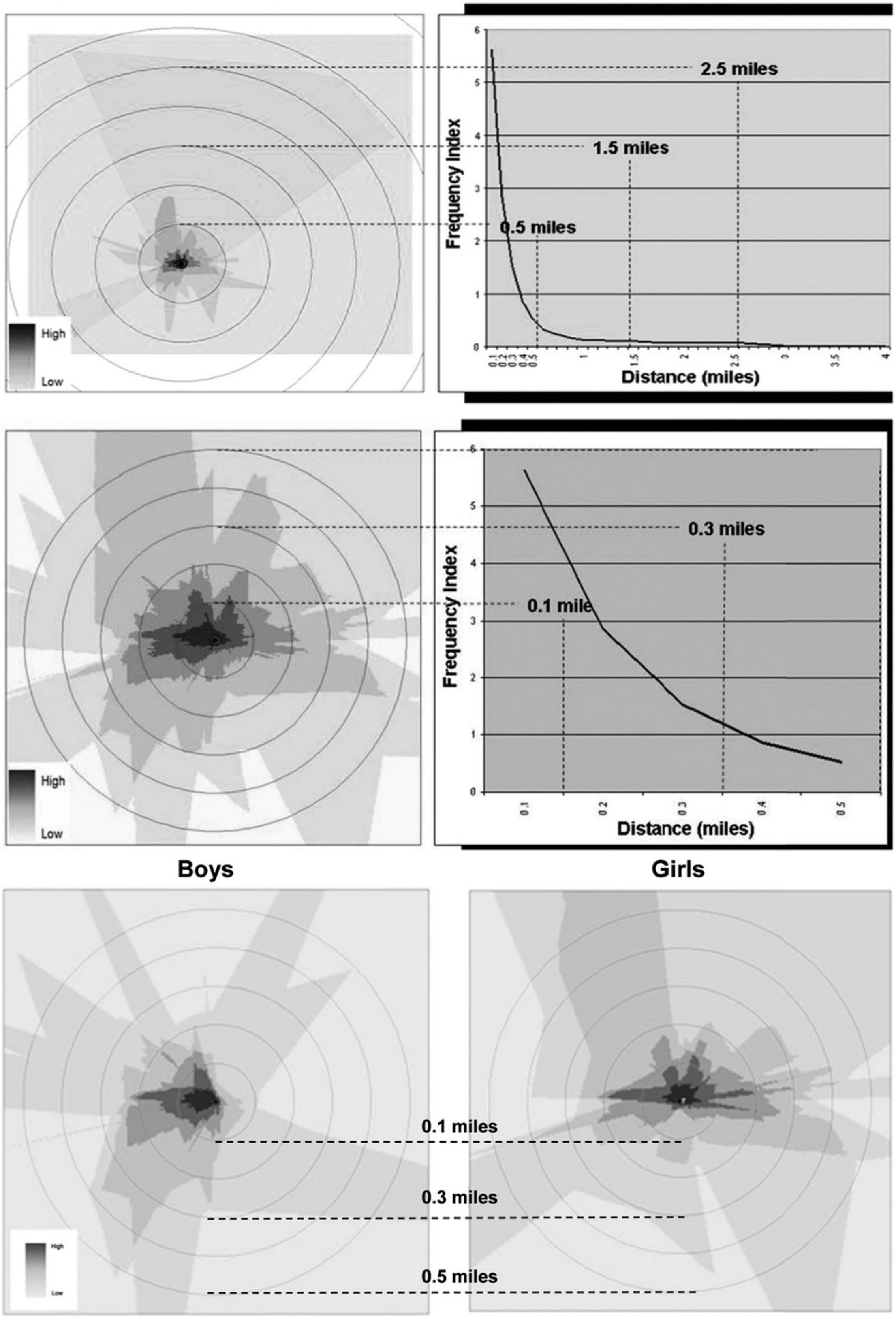

Figure 3. Distance and frequency of visits to the areas around participants' homes.

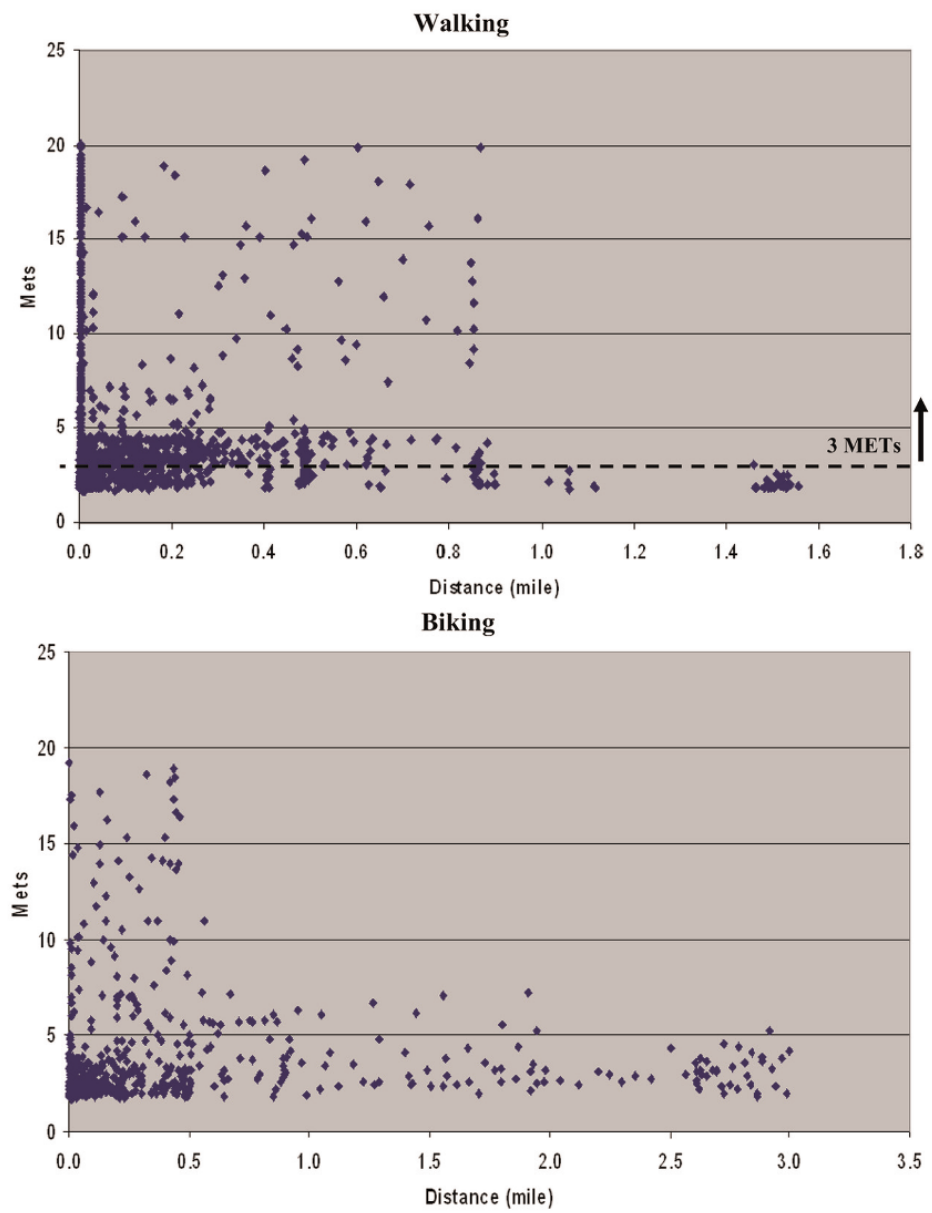

Figure 4. MET intensity as a function of the distance from the participants' homes (walking vs biking GPS points).

ring were visited at least once by the studied youth during the one-week period.

The images on the third row illustrate the frequency of visits by boys and girls within the half-mile ring to help to compare the difference in behaviour of girls and boys in the study. As we can see, there are convex hulls extending to the half-mile boundary in both the left panel and the right-side image. In both images, however, a greater concentration of convex hulls tends to be within the rings smaller than the half-mile. There is no substantial difference between the size of boys' and girls' play neighbourhoods that they visited most often, although girls appears to be traversing slightly larger areas around their homes.

Youth's physical activity varies in intensity across the landscape surrounding their homes. Figure 4 shows MET intensity of walking/jogging/running (upper panel) and bicycling (lower panel) as a function of the distance from the participants' homes based on walking and biking GPS points. Physical activity level in METs is shown on the *y* axis and distance to home on the *x* axis. The dotted thick dark line represents the three MET cut-off points for moderate and vigorous activity. All of the identified walking points are above or close to the cut-off line of three METs. There is a large cluster of points before three-tenths of a mile for walking and then another two smaller clusters around four-tenths of a mile and a half-mile in the upper image. Many walking points are within youth's back and front yards. The biking chart shows that there is a large cluster within three-tenths mile and a smaller cluster around a half-mile.

Figures 3 and 4 show that a half-mile radius around youth's home may be a reasonable boundary for neighbourhoods, but the areas within three-tenths of a mile or a quarter-mile are more frequently used for playing, especially walking. Results from this study suggest that, while there is some variation in the distance that youth traverse while playing around their homes, youth most frequently use the area within three-tenths of a mile or a quarter-mile around their homes for play, especially while on foot.

Conclusion

The detailed space–time–activity trajectories at the individual level, recorded by integrating GPS, travel diary, GIS and accelerometer data offer a novel method for planners to examine and define the spatial extent within which youth play around their homes. Using a mixture of visual and quantitative methods and data, we compared the actual play neighbourhoods of our subjects where most moderate and vigorous activities occurred with the predominant half-mile area. This study suggests that, contrary to common assumptions within the literature, youth do not play within a uniform radius around their homes equally in all directions. This may be a function of the characteristics of their built environment, a possibility that requires further study. The physical activity patterns among youth tend to focus on only one or two directions or sections within a circled neighbourhood, yet often it is built environment attributes within the entire circled neighbourhood that are used to determine the association of the built environment with the physical activity or adiposity of children, youth and adults. Using circled neighbourhoods, such as the half-mile radius, and calculating built environment variables based on these circled neighbourhoods as done in many previous studies may have misrepresented the neighbourhood environment characteristics and their contribution to physical activity by including neighbourhood attributes that youth do not use or experience. More studies in the field of planning and public health are needed to examine the attributes in these one or two directions or sections within a circled neighbourhood that attracted youth physical activities and what built environment characteristics in youth's neighbourhood they are seeking.

We find that, while the half-mile radius for people's neighbourhoods used in many studies may be a reasonable assumption for the general population, it is an overestimate of the area most often traversed by youth on foot or bicycle. A quarter-mile or three-tenths-mile radius is a more accurate estimate of the spatial extent within which youth play. Future studies exploring the influence of the built environment on physical activity need to measure the features of the built environment closer to home (within a smaller radius than one-half mile) to represent youth's play neighbourhood more accurately. Similarly, practising planners who are increasingly developing health-based metrics in their policies and plans need to incorporate more precise measures of how youth use their neighbourhoods. The methodology and findings offered in this paper encourage planners to think more carefully about distance metrics.

This study focused on non-automobile travel while many studies have suggested that only a small proportion of children travel by non-automobile modes. Based on the database and method developed in this study, the study of spatial extent of the neighbourhood with which youth play can be extended to space–time neighbourhoods that are based on all types of travel modes of the participants (Chen *et al.*, 2011).

This study has a small sample size and participants were aged from 10 to 15 years. This age-group may be diverse in terms of their autonomy levels (Sirard *et al.*, 2005). Parental control was not considered in the study, which is one of the key factors in helping to understand children's environmental experience (McMillan, 2005). Future research will require larger, more diverse, samples to explore age-related and sex-related differences in active play in children's and youth's neighbourhood environments. Although the heterogeneity of the neighbourhoods in the present study provides for greater generalisability, future research is needed in other communities that may differ in housing density, population density, street connectivity, crime, and parental willingness to provide autonomy of their children to travel within their wider neighbourhoods. With a larger sample, future studies are needed to test the associations of built environmental variables and neighbourhood composition and the size of the play areas, and to examine how the built environment characteristics are associated with certain parts of the circled neighbourhoods that attract youth physical activities to guide policy and planning decisions. In the present study, all walking, biking, running and playing points such as those in backyards or an open space near subjects' houses are considered as play points. In future research, different types of play should be differentiated to enable a better examination of the relationship of built environment and physical activities. In addition, study participants' perspectives on place and environment can be a good source of data with more participant involvement in future research.

Although GPS provides a means of understanding how people use the built environment at an individual level, it has some limitations. This study had to discard some collected data because of inconsistency between GPS and diary data. First, GPS units tend to lose signals or give errant location information in high-density areas with high-rise buildings and trees. Secondly, GPS can only capture information outdoors. There is a time lag between when GPS starts to gather data and the time people walk out of a building. Thirdly, study subjects can forget to turn on GPS units or leave the units at home. Turning in both datasets at the end of every day by the study subjects through email or a website—to allow researchers to do a quick check on the mismatch while subjects may still be able to recall correctly which data are more accurate—can help to keep more data for the research. Finally, there are some sensitivity concerns on privacy issues related to the use of GPS to track people's daily activity. The development of new technology may help future research on the study of micro- and macro-level youth's behaviour in their immediate vicinity and help planners to shape the built environment for building healthy and sustainable cities and futures.

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