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Are buffers around home representative of physical activity spaces among adults?

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ABSTRACT

Residential buffers are frequently used to assess built environment characteristics relevant to physical activity (PA), yet little is known about how well they represent the spatial areas in which individuals undertake PA. We used System for Observing Play and Recreation in Communities data for 217 adults from five US states who wore an accelerometer and a GPS for three weeks to create newly defined PA-specific activity spaces. These PA spaces were based on PA occurring in bouts of ≥10 min and were defined as 1) the single minimum convex polygon (MCP) containing all of a participant's PA bout minutes and 2) the combination of many MCPs constructed using each PA bout independently. Participants spent a large proportion of their PA bout time outside of 0.5, 1, and 5 mile residential buffers, and these residential buffers were a poor approximation of the spatial areas in which PA bouts occurred. The newly proposed GPS-based PA spaces can be used in future studies in place of the more general concept of activity space to better approximate built environments experienced during PA.

1. Introduction

Theoretical frameworks suggest that built environment characteristics may be points of intervention for developing physical activity (PA) health promotion programs at the population level (McLeroy et al., 1988; Kersell and Milsum, 1985). These built environment characteristics, including attributes of urban design, land use, and transportation systems (Handy et al., 2002), are often assigned based solely on the location of a participant's home, without regard to where their PA actually occurs. Indeed, a systematic review of the literature as of 2009 indicated that 90% of studies on the relationship between the contextual built environment and cardiometabolic risk factors focused solely on the residential environment (Leal and Chaix, 2011), although some recent literature has moved away from this practice (e.g. Rodriguez et al. (2012)). This study therefore examines the relationship between the spatial locations of participant PA and their home addresses to quantitatively evaluate the appropriateness of residential-based built environment exposures for PA behaviors.

Residential-based assignment methods are at odds with the concept of activity space, which represents the overall geographical area in which individuals spend time in their day-to-day lives (Thornton et al., 2011). Many authors have therefore been critical of the use of residential-based demarcations, indicating that it allows for substantial measurement error of built environment attributes (Rainham et al., 2010; Perchoux et al., 2013). Further, residential-based assignment methods have received criticism from both the geography and public health fields, being called, for example, "place-based" instead of "people-based" (Miller, 2007) and the "local" (Cummins, 2007) or "residential" (Chaix et al., 2009) "trap", indicating their failure to measure exposures from the locations in which people actually spend time. Given these various criticisms, many authors have suggested that location-enabled devices could be used to more accurately measure these environmental contexts (Rainham et al., 2010; Kerr et al., 2011; Boruff et al., 2012), particularly for physical activity (Krenn et al., 2011; Maddison and Ni Mhurchu, 2009). Despite this consensus, many researchers still rely on residential-based assignment methods as studies involving global positioning systems (GPS) can be costly, time-intensive, and introduce advanced data management and manipulation challenges.

Understanding the proportion of PA time spent in residential

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buffers is therefore an important step in assessing the accuracy of studies focused solely on the residential environment. Specifically, it will inform the validity of the assumption that the home neighborhood accurately represents built environment characteristics encountered during PA and will provide guidance on whether or not measurement error may be of concern. This study therefore 1) assessed the percent of PA time spent within residential buffers, 2) proposed two new definitions of PA-specific activity space, in contrast to the more general concept of activity space, to represent the spatial areas in which individuals completed bouts of PA measured by GPS over a three-week period, and 3) examined the degree of spatial overlap between these PA activity spaces and traditional residential-defined buffers. Further, differences by sociodemographic characteristics were examined given that these factors may affect how near to home one engages in PA.

2. Methods

2.1. Study population

This study used data collected as part of the System for Observing Play and Recreation in Communities (SOPARC) GPS sub-study. The initial data collection involved recruitment of participants from key parks within five communities (Los Angeles, California; Albuquerque, New Mexico; Chapel Hill and Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania) as well as from residences within one mile of the parks. Participants were eligible for the study if they were ≥18 years old, English-speaking, and ambulatory. Sociodemographic data (age, sex, race/ethnicity, and highest level of education achieved) were collected through a questionnaire. Study staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height of participants at enrollment, respectively, allowing classification of body mass index (BMI, kg/m^2) into categories of normal weight ($< 25\ kg/m^2$), overweight (≥ 25 to $< 30\ kg/m^2$), or obese ($\geq 30\ kg/m^2$).

Participants were asked to concurrently wear an accelerometer to measure PA and a GPS to measure location for three consecutive 1-week periods during the spring, summer, or fall of 2009–2011. Details of the accelerometer and GPS are discussed in detail below. Further participant recruitment and study details are available elsewhere (Evenson et al., 2013a, 2013b; Cohen et al., 2013). Study protocols were approved by appropriate study site affiliated institutional review boards and participants provided written informed consent.

2.2. Physical activity assessment

Participants wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, Florida) accelerometer on the right hip for three consecutive 1-week periods (Evenson et al., 2013b). The accelerometer recorded PA in 1-min epochs and has demonstrated validity (Van Remoortel et al., 2012). Accelerometer non-wear time was identified as ≥90 min of consecutive zero counts, allowing for up to two minutes of nonzero counts if the 30 min before and after the nonzero counts contain no positive counts (Choi et al., 2011). Counts for these non-wear minutes were flagged as missing. The GPS data were then merged with the accelerometer data, including the accelerometer minutes flagged as non-wear, by timestamp.

Moderate to vigorous PA bouts (MVPA-Bs) of at least ten minutes were used to conform with the 2008 PA Guidelines for Americans and the World Health Organization PA recommendations (US Department of Health and Human Services, 2008; World Health Organization, 2010) and to better visualize PA that occurs together spatially. MVPA-Bs were identified based on the Matthews' cut-point (MVPA ≥760 counts/min) (Matthews, 2005), allowing for 20% of the minutes to fall below the cut-point. In addition, a bout had to begin and end with a physically active minute and could not contain more than four consecutive minutes below the cut-point. The analysis considered wearing the accelerometer for at least four, ten-hour days as compliant (Ward et al., 2005), although participants contributed a median (IQR) of 17 (13-20) days of compliant wear.

2.3. Physical activity location monitoring

Geographic location of participants was tracked using a Qstarz BT-Q1000X portable GPS unit (weight, 65 g; dimensions, 72×46×20 mm) with Wide Area Augmentation System (WAAS) enabled to improve accuracy (Evenson et al., 2013a, 2013b). GPS points were recorded in one minute epochs. Participants were asked to wear GPS units concurrently with the ActiGraph GT1M accelerometers for three consecutive one-week periods.

2.4. Residential buffer area creation

Participant home addresses were used to define several residence-based buffers in ArcGIS 10.3.1 (ESRI 2015, Redlands, CA) that span those commonly used in the literature. Home addresses were first geocoded using the 2010 TIGER/Line shape files in ArcGIS 10 and unmatched addresses were geocoded with electronic maps as needed (Evenson et al., 2013b). Residence-based buffers were created with the geoprocessing buffer tool (0.5, 1, and 5 mile circular buffers, encompassing all area 0.5, 1, and 5 miles in Euclidian (straight-line) distance from the home address) and network analyst service areas (0.5, 1, and 5 mile road network buffers, encompassing all area 0.5, 1, and 5 miles in road network distance from the home address). The 0.5 and 1 mile buffers were chosen as they are commonly used in the literature. The 5 mile buffer represents a larger and more inclusive buffer in order to determine which buffer size best captured PA.

2.5. Physical activity space creation

MVPA GPS points that were part of an MVPA-B were used to create two new measures of MVPA space: an overall MVPA space and an independent bout-based MVPA space. These measures were derived from the general concept of activity space, which seeks to describe the space in which individuals conduct day-to-day activities regardless of PA level (Thornton et al., 2011). Typically, activity space is constructed by mapping all of the locations in which a person experiences time during the day. In these analyses, the measures have been adjusted to represent only the space in which individuals were physically active. Specifically, all MVPA GPS points that were part of a MVPA-B during the three weeks were used to create a single overall minimum convex polygon space for each participant (Fig. 1). The minimum convex polygon (convex hull) is the smallest polygon containing all points.

In addition to the overall minimum convex polygon, a MVPA space layer was created for each participant based on their independent MVPA-Bs (Fig. 2). In this case, instead of using all MVPA-B points to create a single, overall MVPA space for each participant, the minimum convex polygon tool in ArcGIS was used to create a space for each MVPA-B separately. These individual bout MVPA spaces were created in a single layer and dissolved by participant (removing double counting of overlapping land area across the bouts) to use in comparison with the residential-based buffers.

The bout-based method is proposed as an alternative to the single, overall MVPA space to potentially limit inclusion of large sections of land unused for PA between MVPA-B locations as could occur in creating overall MVPA spaces (Figs. 1 and 2) and is therefore thought to be more representative of the spatial areas in which participants engage in MVPA-Bs. This approach has been previously proposed for summarizing spatial data that is unevenly distributed (Bachi, 1962). In all cases of MVPA space creation, the data were first cleaned to remove bouts that were unreasonably far (> 35 miles) from the participant's home address, allowing a PA location to require travel up to twice the average daily distance traveled in the five study states (US Department

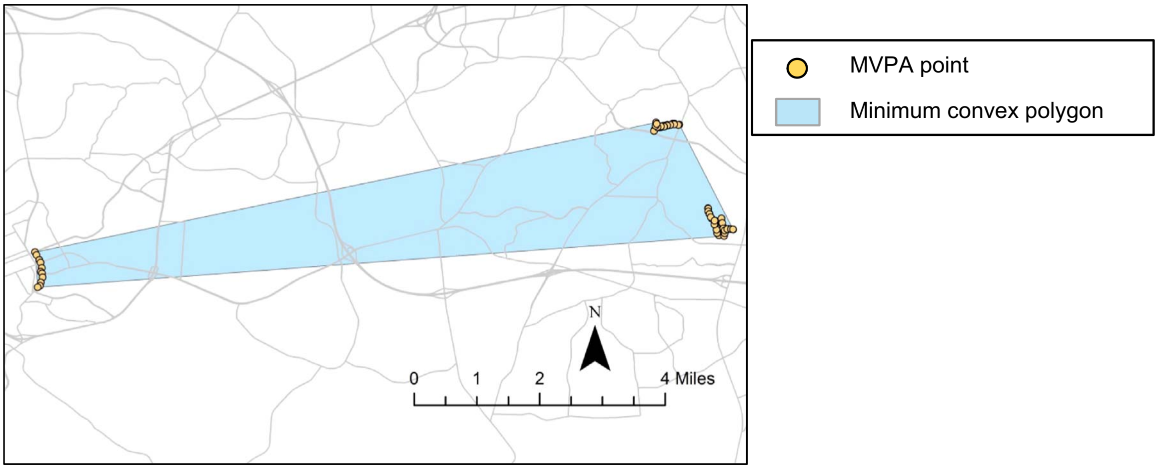

Fig. 1. Minimum convex polygon of *overall* MVPA space compared with actual MVPA GPS points during three MVPA bouts from one individual (simulated data).

of Transportation National Household Travel Survey, 2009). Bouts > 35 miles from home were allowed for one participant who had daily (and therefore routine) PA bouts at a location where they also spent a considerable amount of non-PA time daily. In total, 3.9% of points, many of which were out of state, were removed to prevent these outliers from influencing results, representing MVPA-Bs that are not likely part of routine behavior.

2.6. Geographic and statistical analyses

Results are presented in relation to both time and space. First, the number of a participant's 1-min bout-based MVPA GPS points located within their residential buffer was identified using ArcGIS 10.3.1. Results were exported to SAS 9.3 (Cary, NC) to calculate the percent of MVPA-B time spent in the residential buffers for each participant. Second, layers of residential-based buffers were overlaid with the overall and individual bout-based MVPA layers seen in example Fig. 3. ArcGIS 10.3.1 was then used to calculate 1) the percent of land area in residential-based buffers used for MVPA-Bs [C/A in Fig. 3] and 2) the percent of land area in MVPA spaces located within residential-based buffers [C/B in Fig. 3]. For all analyses, results are presented overall and by sociodemographic factors (gender, age, race, education), BMI, and state of recruitment, with differences examined by Kruskal Wallis tests. All analyses were completed separately by state to allow use of a site-appropriate projected coordinate system (North American Datum 1983 State Plane).

The built environment may indirectly influence decisions to be physically active at home, where a large proportion of MVPA occurs (Holliday, 2017). Yet, characteristics of the built environment experienced when adults are physically active away from the home are also of interest. Therefore, a sensitivity analysis was completed after removing MVPA-B minutes occurring within a participant's home or yard.

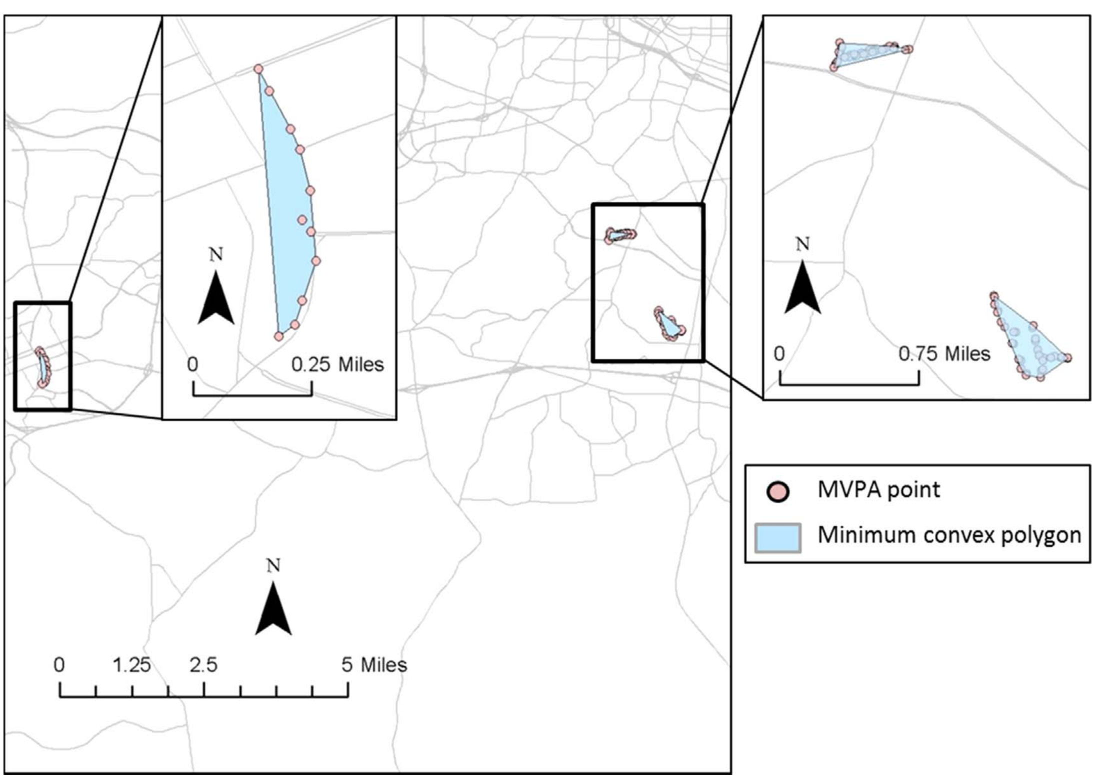

Fig. 2. Individual MVPA bout defined minimum convex polygon MVPA space compared with actual MVPA GPS points during the three MVPA bouts from one individual displayed in Fig. 1(simulated data).

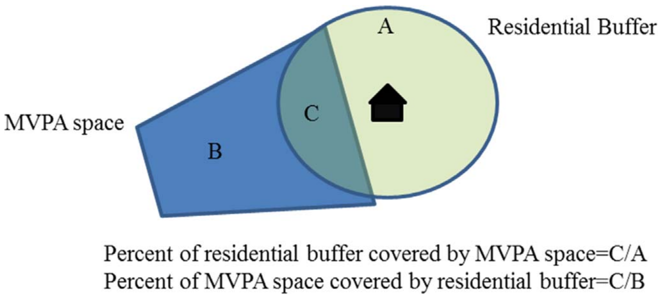

Fig. 3. Example of residential buffer and MVPA space outcome definitions.

MVPA-B minutes in a participant's home or yard were identified using a newly developed coding protocol described elsewhere (Holliday, 2017).

3. Results

The SOPARC GPS sub-study enrolled 248 participants of whom thirteen were excluded due to missing data (two who contributed no accelerometer data and eleven who had all missing data for GPS points), 12 were excluded due to non-compliant accelerometer wear (less than four 10-h days), and 6 had home addresses that could not be geocoded, leaving 217 participants for analysis. The participants contributed a median 17 days of at least 10 h of wear (interquartile range: 13–20).

Participants included in the analysis had similar sociodemographic characteristics as those initially enrolled. Included participants ranged from 18 to 85 years of age [mean (SD): 41.0 (15.7)] and 45% were male (Table 1). Participants were from varied racial/ethnic (50% Non-Hispanic White, 24% Non-Hispanic Black, 16% Hispanic, 10% Other (Asian/Pacific Islander, Native American, or multi-racial)) and educational backgrounds (22% ≤high school education, 22% some college or vocational school, 56% college or post graduate degree). BMI was evenly distributed, with 34% under or normal weight, 33% overweight, and 33% obese. The majority of Non-Hispanic Blacks were recruited in Ohio and Pennsylvania (63%) and Hispanics in New Mexico and California (74%). Most individuals with a post-graduate education were recruited from North Carolina (42%) and 66% of those with a high school education or less were recruited from Pennsylvania and Ohio.

3.1. Physical activity time spent in residential buffers

The median percent of MVPA-B time spent within variously sized residential buffers ranged from 39% to 74%, with higher median percentages in larger residential buffers, although there was variation across participants (e.g., median (IQR) percent of MVPA-B minutes spent within 0.5 mile network buffers: 39.3% (15.4–59.9); Table 2). Median percent of MVPA-B time spent in residential buffers varied by sociodemographic characteristics (Table 3). For example, age (p=0.03) and recruitment state (p=0.02) were associated with MVPA-B time spent in 0.5 mile network buffers. Older adults and those recruited from New Mexico consistently spent more of their MVPA-B time in 0.5 mile residential buffers (e.g. median 45% vs 32% MVPA-B minutes in 0.5 mile network buffers for older vs. younger adults and median 49% vs 29% MVPA-B minutes in 0.5 mile network buffers for participants recruited from New Mexico vs. from North Carolina). More differences were noted after expanding to a five mile circular residential buffer, with older adults, those recruited from New Mexico, males, those with normal weight, and Non-Hispanic whites completing more of their MVPA-B minutes within the 5 mile circular residential buffer (Table S1). For example, racial/ethnic differences were noted (p=0.04) with Non-Hispanic Blacks spending less of their MVPA-B minutes within the 5 mile circular residential buffers than other race/ethnic groups (e.g. median 61% PA bout minutes vs 80% for Non-Hispanic Whites).

Table 1
Sociodemographic characteristics of participants in the SOPARC GPS sub-study, 2009–2011.

		Sample[a] N	Sample[a] %	Total MVPA-B minutes/participant[b] Median (IQR)
Overall Number		217	–	
Sex	Male	97	44.7	568 (316, 1014)
	Female	120	55.3	428 (209, 850)
Age	18–35	99	45.6	498 (276, 868)
	36–59	81	37.3	473 (245, 1004)
	60–85	37	17.1	568 (213, 943)
Race/Ethnicity	Non-Hispanic White	109	50.2	580 (294, 1091)
	Non-Hispanic Black	51	23.5	366 (174, 609)
	Hispanic	35	16.1	435 (246, 689)
	Other	21	9.7	638 (349, 877)
	Missing	1	0.5	
Education	High School/GED or less	47	21.7	330 (155, 664)
	Some college or vocational	48	22.1	337 (226, 674)
	College or higher	122	56.2	574 (366, 1020)
BMI	Under or Normal Weight	74	34.1	661 (366, 1033)
	Overweight	71	32.7	557 (366, 900)
	Obese	72	33.2	275 (120, 552)
Recruitment Location	Los Angeles, CA	46	21.2	513 (304, 966)
	Albuquerque, NM	45	20.7	469 (197, 671)
	Chapel Hill and Durham, NC	47	21.7	683 (425, 1104)
	Columbus, OH	40	18.4	352 (164, 628)
	Philadelphia, PA	39	18.0	403 (226, 913)
Recruitment Location	Household	46	21.2	437 (274, 687)
	Park	171	78.8	498 (250, 962)

BMI, body mass index; CA, California; IQR, interquartile range; MVPA-B, moderate to vigorous physical activity in bouts of at least 10 min; NM, New Mexico; NC, North Carolina; OH, Ohio; PA, Pennsylvania.
[a] Those who were included in the analysis after exclusions.
[b] Moderate to vigorous physical activity ≥760 counts/minute occurring in bouts of 10 min or more over three weeks.

Table 2
Median (interquartile range) percent of moderate to vigorous physical activity bout minutes over three weeks located within residential buffers per participant in the SOPARC GPS sub-study, 2009–2011 (N=217).

	Median (IQR) MVPA-B minutes[a]	Median (IQR) percent MVPA-B minutes[a] in buffer
Total MVPA Minutes	491 (268, 913)	
0.5 mile network	157 (57–328)	39.3 (15.4, 59.9)
0.5 mile circular	173 (71–356)	41.6 (18.6, 63.9)
1 mile network	176 (70–386)	43.6 (19.7, 69.2)
1 mile circular	187 (79–414)	48.1 (22.6, 73.2)
5 mile network	270 (106–529)	65.9 (41.6, 90.7)
5 mile circular	289 (126–569)	74.1 (47.7, 91.7)
Away from Home MVPA-B Minutes	303 (146, 622)	
0.5 mile circular	21 (0–109)	9.5 (0.0, 35.0)
1 mile circular	33 (0–168)	15.2 (0.7, 44.3)
5 mile circular	142 (27–330)	54.8 (20.1, 84.9)

MVPA-B, moderate to vigorous physical activity in bouts of at least 10 min; IQR, interquartile range.
[a] MVPA ≥760 counts/minute occurring in bouts of 10 min or more over three weeks.

Males and females had similar patterns for small buffers; however males completed more of their MVPA-B time within 5 miles of home than females (i.e. median 80% vs. 69% for 5 mile circular buffers, p=0.04).

Table 3
Median (interquartile range) percent of moderate to vigorous physical activity bout minutes over three weeks located within residential buffers by sociodemographic characteristics of participants in the SOPARC GPS sub-study, 2009–2011 (N=217).

		0.5 mile network	p[a]	0.5 mile circular	p[a]	1 mile network	p[a]	1 mile circular	p[a]
Age	18–35	32.4 (13.3, 50.7)	0.03	38.4 (17.1, 57.9)	0.05	40.5 (19.6, 58.7)	0.05	43.3 (21.1, 68.4)	0.07
	36–59	41.6 (12.6, 61.2)		42.8 (15.0, 61.9)		45.6 (15.2, 70.4)		49.3 (20.3, 71.7)	
	60–85	45.3 (31.8, 81.4)		47.7 (31.8, 83.5)		59.2 (32.3, 85.4)		62.7 (36.1, 88.5)	
Gender	Female	39.6 (15.7, 58.2)	0.8	42.8 (19.6, 64.9)	0.7	44.4 (21.0, 69.7)	0.8	48.3 (29.7, 73.7)	1.0
	Male	39.3 (15.4, 60.1)		39.3 (16.3, 63.2)		43.3 (19.6, 69.2)		47.9 (20.3, 72.9)	
Race/Ethnicity	Non-Hispanic White	42.0 (16.2, 64.5)	0.7	44.8 (19.5, 72.0)	0.5	47.4 (20.3, 72.7)	0.4	49.3 (30.5, 76.9)	0.1
	Non-Hispanic Black	35.9 (11.7, 56.8)		38.0 (12.9, 58.2)		38.4 (12.9, 62.5)		38.4 (12.9, 62.7)	
	Hispanic	38.3 (12.6, 61.0)		39.4 (15.4, 66.4)		45.9 (21.9, 78.4)		49.9 (21.9, 87.3)	
	Other	44.2 (20.1, 56.6)		45.7 (20.1, 56.6)		46.0 (20.1, 59.2)		46.0 (20.1, 61.2)	
Education	≤High School	43.0 (21.9, 73.3)	0.3	45.7 (29.0, 78.8)	0.3	52.4 (34.4, 82.7)	0.1	52.4 (34.4, 82.7)	0.2
	Some College	33.5 (13.8, 65.2)		39.2 (17.9, 67.4)		39.9 (18.0, 72.9)		48.3 (26.1, 77.5)	
	College Degree	39.9 (14.8, 56.0)		42.8 (17.1, 60.4)		43.4 (16.8, 62.5)		46.3 (20.3, 69.4)	
Body Mass Index	Normal	34.5 (16.0, 52.9)	0.5	38.8 (19.5, 63.9)	0.9	42.0 (19.7, 68.9)	0.9	46.4 (21.7, 73.2)	1.0
	Overweight	42.8 (19.7, 58.2)		43.0 (20.0, 61.5)		45.9 (20.7, 69.8)		48.4 (24.4, 72.9)	
	Obese	41.6 (12.4, 66.1)		43.3 (13.9, 66.4)		48.0 (14.1, 71.3)		50.2 (18.9, 75.0)	
Recruitment State	California	37.3 (15.4, 58.2)	0.02	41.4 (17.3, 66.4)	0.04	46.9 (20.6, 72.7)	0.04	48.9 (24.4, 77.4)	0.08
	New Mexico	49.3 (29.0, 81.5)		52.9 (31.6, 85.4)		57.2 (32.3, 87.6)		63.8 (36.1, 88.5)	
	North Carolina	29.2 (12.9, 54.8)		33.3 (14.8, 61.2)		37.4 (14.3, 61.1)		45.4 (15.4, 69.6)	
	Ohio	42.2 (8.5, 63.6)		44.4 (15.0, 71.8)		45.2 (15.0, 72.1)		45.5 (15.3, 75.7)	
	Pennsylvania	35.9 (11.3, 47.7)		39.4 (18.6, 52.4)		41.0 (19.4, 53.7)		41.6 (22.7, 54.8)	

[a] Kruskal Wallis *p-value*.

3.2. Proportion of residential buffers used for physical activity

The median percent of 0.5 and 1 mile residential buffers covered by MVPA spaces derived from mapping all of a participant's MVPA-B points occurring during the three weeks into a single minimum convex polygon ranged from 33% to 44% (Table 4, defined as C/A in Fig. 3). In contrast, the median percent of residential buffers covered by MVPA spaces derived from mapping independent MVPA-Bs into multiple minimum convex polygons was 3% or less. When considering sociodemographic characteristics, differences in use of residential buffer areas for MVPA-Bs by race/ethnicity, education, BMI, and recruitment state were noted (e.g., p=0.03, 0.004, <0.0001, and <0.0001, respectively, for the proportion of 0.5 mile network buffers overlapped by the overall MVPA space; Table 5, Supplemental Tables S2 and 3). The proportion of residential buffers used for MVPA-Bs was smallest for Non-Hispanic Blacks and Hispanics, increased with increasing education, decreased with increasing BMI, and was highest for those recruited from California and North Carolina, regardless of the buffer size (0.5, 1, or 5 mile) or method (circular, network). For example, the overall minimum convex polygon covered the 0.5 mile network buffer a median 58% for Non-Hispanic Whites and 51% for other race/ethnicity vs. 30% for Non-Hispanic Blacks and 40% for Hispanics; 57% for those with a college degree versus 31% for those with a high school education or less and 45% for those with some college; 74% for those of normal weight vs. 48% for overweight and 25% for obese individuals; and 87% for those recruited from California and 82% of those recruited from North Carolina participants vs 31% for those recruited from New Mexico, 24% for those recruited from Ohio, and 38% for those recruited from Pennsylvania.

Table 4
Median (interquartile range) percent of residential buffers covered by moderate to vigorous physical activity spaces per participant in the SOPARC GPS sub-study, 2009–2011 (N=217).

	Minimum convex polygon[a]	Minimum convex polygon bout[b]
Total MVPA-B Minutes		
0.5 mile network buffer	44.1 (17.2, 95.1)	3.2 (0.1, 21.0)
0.5 mile circular buffer	40.0 (13.0, 79.5)	1.9 (0.0, 12.6)
1 mile network buffer	36.2 (8.2, 70.8)	1.1 (0.0, 8.2)
1 mile circular buffer	33.4 (7.3, 56.1)	0.6 (0.0, 4.8)
5 mile network buffer	11.2 (1.1, 28.9)	0.1 (0.0, 0.5)
5 mile circular buffer	8.0 (0.8, 20.4)	0.1 (0.0, 0.3)
Away from Home MVPA-B Minutes		
0.5 mile circular buffer	34.3 (0.2, 79.5)	1.2 (0.0, 11.3)
1 mile circular buffer	25.4 (0.5, 56.1)	0.4 (0.0, 4.4)
5 mile circular buffer	6.7 (0.3, 18.7)	0.1 (0.0, 0.3)

MVPA-B, moderate to vigorous physical activity in bouts of at least 10 min.
[a] Minimum convex polygon for each participant derived from all of their MVPA bout minutes.
[b] Multiple minimum convex polygons for each participant derived from each individual bout of MVPA.

3.3. Proportion of physical activity spaces overlapped by residential buffers

Commonly used 0.5 and 1 mile circular and network residential buffers covered a median 2–55% of MVPA spaces, with more of the individual bout MVPA spaces covered (medians ranged from 21% to 55%) than the overall MVPA spaces (medians ranged from 2% to 12%) (Table 6, C/B in Fig. 3). However, a large proportion of overall and bout-based MVPA space was located within 5 mile circular and network residential buffers (medians ranged from 78% to 99%). Results again varied by sociodemographic characteristics, including age, education, and recruitment state (e.g. p=0.0006, 0.0001, <0.0001, respectively, for overlap between 1 mile network buffers and overall MVPA space; Table 7, Supplemental Tables S4 and 5). In general, residential buffers covered a larger portion of MVPA spaces for older adults, those with a high school education or less, and those recruited from New Mexico and Pennsylvania (e.g., 1 mile network buffers covered a median 16% of the overall MVPA space for older adults vs 6% for younger adults; 16% for those with a high school education or less vs 4% for those with a college degree; and 18% for participants recruited from New Mexico and 15% for Pennsylvania vs 2–6% for those recruited from other sites). Despite these differences, the 0.5 and 1 mile residential buffers in general covered only a small portion of the MVPA spaces, particularly for the overall MVPA spaces.

Table 5
Median (interquartile range) percent residential network buffers covered by moderate to vigorous physical activity spaces stratified by sociodemographic characteristics in the SOPARC GPS sub-study, 2009–2011 (N=217).

		0.5 mile network buffer				1 mile network buffer			
		Minimum convex Polygon[a]	p[b]	Minimum convex Polygon Bout[c]	p[b]	Minimum convex Polygon[a]	p[b]	Minimum convex Polygon Bout[c]	p[b]
Age	18–35	41.5 (18.4, 94.2)	0.9	3.6 (0.1, 18.7)	0.5	33.2 (10.0, 71.2)	1.0	2.1 (0.0, 8.2)	0.6
	36–59	49.6 (19.6, 91.1)		1.9 (0.1, 20.8)		39.1 (11.6, 64.3)		0.5 (0.0, 7.4)	
	60–85	70.4 (2.2, 99.8)		6.9 (0.0, 24.2)		47.7 (1.0, 81.4)		1.5 (0.0, 11.4)	
Gender	Female	43.7 (6.0, 94.3)	0.4	1.3 (0.1, 19.4)	0.1	36.8 (3.9, 67.1)	0.7	0.6 (0.0, 7.4)	0.1
	Male	44.1 (22.1, 97.3)		4.6 (0.1, 21.5)		34.7 (12.5, 77.1)		1.9 (0.1, 9.8)	
Race/Ethnicity	Non-Hispanic White	57.9 (22.1, 99.6)	0.03	9.8 (0.1, 22.4)	0.01	47.7 (12.5, 82.8)	0.01	3.4 (0.1, 10.9)	0.008
	Non-Hispanic Black	30.0 (0.9, 70.1)		0.7 (0.0, 7.8)		21.9 (0.5, 47.7)		0.2 (0.0, 3.4)	
	Hispanic	39.5 (19.6, 68.1)		1.0 (0.1, 15.9)		33.2 (15.2, 51.3)		0.5 (0.0, 6.8)	
	Other	50.7 (3.4, 100.0)		10.0 (0.1, 40.2)		47.3 (5.5, 88.6)		2.1 (0.0, 20.6)	
Education	≤High School	30.5 (3.2, 64.8)	0.004	2.0 (0.2, 9.2)	0.006	21.9 (0.8, 39.2)	0.0005	0.5 (0.0, 3.2)	0.007
	Some College	44.9 (8.6, 99.8)		0.5 (0.0, 14.7)		31.3 (5.6, 75.0)		0.2 (0.0, 5.6)	
	College Degree	56.6 (22.3, 100.0)		11.0 (0.1, 26.1)		47.4 (13.8, 85.6)		3.4 (18.3, 95.5)	
BMI	Normal	73.5 (30.5, 100.0)	< 0.0001	9.9 (0.3, 27.4)	0.0002	50.8 (27.3, 88.7)	< 0.0001	3.8 (0.1, 9.2)	0.0008
	Overweight	48.0 (21.2, 100.0)		6.9 (0.1, 21.5)		38.8 (12.8, 85.6)		1.9 (0.0, 10.9)	
	Obese	24.5 (0.3, 65.8)		0.2 (0.0, 8.9)		17.4 (0.3, 40.4)		0.1 (0.0, 4.0)	
Recruitment state	California	87.0 (44.5, 100.0)	< 0.0001	16.0 (0.4, 34.4)	0.0002	62.5 (33.2, 97.0)	< 0.0001	6.5 (0.5, 18.2)	< 0.0001
	New Mexico	30.8 (3.2, 88.8)		1.3 (0.0, 15.1)		23.9 (2.4, 47.7)		0.4 (0.0, 6.0)	
	North Carolina	82.0 (26.7, 100.0)		10.6 (0.1, 32.3)		63.9 (25.3, 92.1)		4.4 (0.1, 15.9)	
	Ohio	23.8 (0.1, 43.4)		0.1 (0.0, 6.9)		13.2 (0.2, 36.4)		0.1 (0.0, 1.6)	
	Pennsylvania	38.1 (6.2, 73.4)		2.2 (0.1, 17.9)		23.7 (4.4, 49.2)		0.5 (0.0, 6.2)	

BMI, body mass index.
[a] Minimum convex polygon for each participant derived from all of their MVPA bout minutes.
[b] Kruskal Wallis *p-value*.
[c] Multiple minimum convex polygons for each participant derived from each individual bout of MVPA.

Table 6
Median (interquartile range) percent of moderate to vigorous physical activity spaces covered by residential buffers per participant in the SOPARC GPS Sub-Study, 2009–2011 (N=217).

	Minimum convex polygon[a]	Minimum convex polygon bout[b]
Total MVPA-B minutes		
0.5 mile network buffer	1.8 (0.4, 9.3)	21.0 (1.8, 56.7)
0.5 mile circular buffer	4.3 (1.1, 21.9)	30.7 (2.8, 67.5)
1 mile network buffer	6.9 (1.5, 27.3)	43.6 (2.9, 83.5)
1 mile circular buffer	12.4 (3.3, 39.1)	55.2 (8.0, 91.8)
5 mile network buffer	77.5 (34.5, 100.0)	97.6 (50.2, 100.0)
5 mile circular buffer	91.5 (52.1, 100.0)	99.3 (62.0, 100.0)
Away from Home MVPA-B Minutes		
0.5 mile circular buffer	1.9 (0.1, 8.2)	15.3 (0.0, 54.2)
1 mile circular buffer	7.5 (1.1, 26.2)	31.4 (0.0, 86.8)
5 mile circular buffer	87.0 (36.6, 100.0)	97.3 (45.1, 100.0)

MVPA-B, moderate to vigorous physical activity in bouts of at least ten minutes.
[a] Minimum convex polygon for each participant derived from all of their MVPA bout minutes.
[b] Multiple minimum convex polygons for each participant derived from each individual bout of MVPA.

3.4. Results limited to non-home physical activity

Participant characteristics for those with MVPA-Bs away from home are described in Table S6. In sensitivity analyses limited to MVPA-Bs occurring away from the participant's home, a much smaller percentage of non-home MVPA-B time occurred within the residential buffers (medians ranged from 10% to 55%, Table 2). Differences by sociodemographic characteristics were again noted, but patterns differed in some cases from those seen when using total MVPA-B time (Supplemental Table S7). For example, differences by BMI were noted (e.g. $p=0.04$ for 1 mile circular buffers), with normal weight individuals having more of their away from home MVPA-B time within the circular residential buffers than did overweight or obese participants, a pattern not previously seen when considering all MVPA-B minutes. Additionally, differences by recruitment state were noted ($p=0.008$ for 1 mile circular buffers), with participants recruited from California, North Carolina, and Pennsylvania having more of their away from home MVPA-B time in 0.5 and 1 mile residential buffers than did those recruited from New Mexico, again contrary to what was observed when using total MVPA-B time. In contrast, the spatial overlap between residential buffers and MVPA spaces was similar when considering away from home MVPA-B time as when total MVPA-B time was used (Tables 4 and 6) and differences by sociodemographic characteristics were also generally similar (Supplemental Tables S8–11). One exception was the importance of age for the percent of MVPA spaces covered by residential buffers when considering all MVPA-B points versus its relative unimportance when considering away from home MVPA-B minutes.

4. Discussion

This study supports the body of literature cautioning against use of residential buffers to assign built environment characteristics (Rainham et al., 2010; Perchoux et al., 2013). Residential buffers of varying sizes may not be representative of the spatial areas in which MVPA-Bs occur, both when considering the proportion of MVPA-B time spent within residential buffers and in considering the spatial overlap between residential buffers and the newly proposed MVPA activity spaces. Of the two newly proposed definitions of MVPA space, the individual bout-based method may conceptually most closely approximate the spatial area in which individuals are physically active given that it removes large areas of land unused for PA included in the overall MVPA space definition.

Adults appear to spend a large proportion of their MVPA-B time outside of residential buffers. In the present study, SOPARC GPS

Table 7
Median (interquartile range) percent of moderate to vigorous physical activity spaces covered by residential network buffers stratified by sociodemographic characteristics in the SOPARC GPS sub-study, 2009–2011 (N=217).

		Minimum convex polygon[a]				Minimum convex polygon bout[b]			
		0.5 mile network buffer	p[c]	1 mile network buffer	p[c]	0.5 mile network buffer	p[c]	1 mile network buffer	p[c]
Age	18–35	1.6 (0.4, 7.2)	0.0006	5.6 (1.1, 16.4)	0.0006	17.0 (2.0, 59.3)	0.09	38.1 (3.0, 80.7)	0.03
	36–59	1.2 (0.3, 7.2)		4.1 (1.2, 25.9)		20.6 (0.9, 43.2)		37.6 (1.9, 76.1)	
	60–85	5.6 (2.0, 35.2)		15.8 (7.6, 79.4)		34.7 (3.6, 89.3)		75.5 (7.7, 92.5)	
Gender	Female	1.8 (0.5, 7.6)	0.9	6.9 (1.6, 24.9)	0.9	15.8 (1.3, 49.6)	0.2	36.0 (2.3, 80.0)	0.2
	Male	1.8 (0.4, 11.5)		6.9 (1.2, 33.9)		24.1 (3.6, 61.3)		55.6 (6.1, 85.7)	
Race/Ethnicity	Non-Hispanic White	2.0 (0.4, 7.6)	0.5	7.2 (1.5, 21.3)	0.4	22.9 (2.7, 51.2)	0.8	52.4 (5.8, 85.3)	0.5
	Non-Hispanic Black	2.0 (0.2, 19.0)		8.0 (1.3, 49.8)		15.1 (0.5, 55.9)		30.0 (0.9, 78.2)	
	Hispanic	1.6 (0.6, 14.6)		5.9 (2.4, 35.7)		19.2 (1.3, 59.7)		44.3 (3.0, 84.2)	
	Other	0.7 (0.2, 2.9)		3.9 (0.8, 9.1)		22.0 (9.0, 48.6)		34.4 (2.3, 61.8)	
Education	≤High School	5.9 (0.9, 30.0)	< 0.0001	16.4 (2.4, 56.0)	0.0001	59.7 (6.0, 90.1)	0.003	78.2 (13.9, 99.9)	0.007
	Some College	2.4 (0.8, 17.3)		9.3 (2.9, 43.4)		13.1 (1.2, 43.0)		42.1 (2.9, 82.9)	
	College Degree	1.1 (0.2, 3.6)		4.2 (1.0, 12.2)		17.7 (1.9, 37.9)		36.0 (2.3, 70.3)	
Body mass index	Normal	1.4 (0.3, 6.1)	0.1	5.0 (1.5, 19.5)	0.09	22.0 (1.8, 50.3)	0.6	46.3 (7.7, 82.0)	0.9
	Overweight	1.7 (0.5, 5.9)		5.6 (1.4, 17.6)		23.2 (2.6, 59.9)		47.3 (5.4, 80.7)	
	Obese	3.0 (0.5, 19.3)		10.8 (1.6, 49.1)		14.6 (0.9, 58.7)		37.9 (2.0, 90.2)	
Recruitment state	California	1.6 (0.6, 7.9)	< 0.0001	5.9 (2.1, 35.7)	< 0.0001	20.4 (4.1, 42.7)	0.03	44.5 (11.8, 72.3)	0.02
	New Mexico	5.6 (0.5, 19.3)		17.6 (2.6, 40.3)		32.7 (2.6, 64.6)		76.1 (2.7, 98.4)	
	North Carolina	0.5 (0.2, 2.0)		2.1 (0.8, 6.9)		12.7 (0.6, 32.7)		22.8 (1.0, 55.6)	
	Ohio	1.3 (0.2, 9.4)		5.1 (1.0, 25.8)		16.5 (0.3, 62.8)		41.3 (0.6, 87.7)	
	Pennsylvania	4.9 (1.5, 26.0)		14.7 (5.4, 56.4)		37.9 (1.9, 77.3)		56.8 (5.4, 91.2)	

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes.
[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity.
[c] Kruskal Wallis *p-value*.

participants completed nearly 60% of total MVPA-B time outside of 0.5 mile residential buffers. Even using a large buffer of 5 miles, 25% of MVPA-B time occurred outside of the buffer. These results agree with those of Troped et al. and Hillsdon et al., who report that nearly 80% of MVPA occurred outside a 1 km residential buffer for Massachusetts trail-users (Troped et al., 2010) and that 60% of outdoor light, moderate, and vigorous PA was outside a 0.5 mile residential buffer for participants from North West England (Hillsdon et al., 2015).

Certain sociodemographic characteristics appear to be associated with the proportion of MVPA-B time spent within residential buffers. In this study, the oldest adults spent more of their MVPA-B time within residential buffers than younger participants, an expected observation given documented reduced mobility of older adults in the United States (Collia et al., 2003). Additionally, participants from North Carolina spent the smallest proportion of MVPA-B time in their residential buffers. This was also not unexpected given that the North Carolina site was the least urban of the five sites. Therefore, these participants may have to travel farther to reach destinations for MVPA, or they may have fewer destinations easily reachable by active transport. These stratified results agree with work by Hillsdon et al. in that both suggest that geographic factors (recruitment site and urbanicity, respectively) are associated with the proportion of PA time spent outside buffers (Hillsdon et al., 2015). In contrast, the results of the present study suggested age but not education (a marker of socioeconomic status) are associated with the proportion of MVPA-B time outside of a 0.5 mile network buffer, but similar work by Hillsdon et al. in England found that age was not associated with this proportion whereas area level affluence (another marker of socioeconomic status) was (Hillsdon et al., 2015). Although differences in the percent of MVPA-B time occurring within traditional 0.5 and 1 mile buffers varied by some sociodemographic factors, the greatest percent observed for any single group was less than 64%, suggesting that these buffers do not adequately capture MVPA-B time for any sociodemographic group.

Few studies have examined the spatial overlap between health-behavior specific activity space and residential buffers as was done in this study for MVPA. Villanueva et al. found that children only used 25% of their neighborhood as defined by a circular buffer (Villanueva et al., 2012). However, the study does not describe the proportion of the children's activity spaces encompassed by residential circular buffers nor do they indicate the proportion of time spent in specific health behaviors, like PA, within these overlapping spatial areas. Similarly, others have found that the percent of general activity space (not limited to that used for PA) overlapping residential buffers of older adults is small (Hirsch et al., 2014). The present study expands this work by considering both the amount of MVPA-B time spent within residential buffers as well as the spatial overlap between residential buffers and activity spaces specific to MVPA.

The adults in this study used a very small proportion of their residential buffers for MVPA-Bs regardless of the buffer size, particularly when compared with the proportion of MVPA-B time spent within those buffers. This is expected given our observation that a large proportion of MVPA-B time that occurs within a residential buffer occurs at the participant's home (Holliday, 2017). While differences by sociodemographic factors, including race, education, BMI, and recruitment state, were noted, these differences for 0.5 mile buffers were consistently between groups that used approximately 10% of their buffer for MVPA-Bs vs those who used ≤2%, a difference that may not be practically significant. Although the difference was small, the groups who did use the largest portion of their buffers for MVPA-Bs were those who are traditionally known to complete more MVPA: non-Hispanic whites, those with more education, and those with a normal BMI. Therefore, a potential intervention point for reducing disparities in MVPA may be to focus on increasing MVPA near a participant's home. Participants from North Carolina and California also used the largest proportion of their buffer area for MVPA-Bs. This was surprising given that participants from Ohio and New Mexico spent a much larger proportion of their MVPA-B time within their buffers. However, Ohio and New Mexico participants also completed most of their buffer MVPA-B time in the home whereas those from California and North Carolina still completed a modest proportion of MVPA-Bs within their buffer but outside of their home. This is an interesting finding and encourages future study that specifically examines factors associated with MVPA that occurs near participant homes, but excludes MVPA that occurs within the home.

Residential buffers contained a modest proportion of MVPA-B activity space area, although proportions were fairly high for some groups. One mile buffers contained nearly 80% of MVPA-B activity space area for the oldest adults, those with the lowest education, and those from New Mexico, indicating that one mile buffers capture a large proportion of the spatial extent of MVPA-Bs for these individuals. Despite this, the groups still used a small proportion of their residential buffers for MVPA-Bs. Together, these findings suggest that the spatial extent of the MVPA-B area within residential buffers is relatively small, discouraging assignment of built environment characteristics based on the entire residential buffer.

One limitation of this study is that the participant selection method and non-representative nature of the sample hinders generalizability to a larger population. Further, the differences observed by recruitment site suggest that these patterns may vary by location, necessitating sampling from a broader geographic area than was completed within this study. This study included MVPA using a threshold that likely includes PA achieved through moderate lifestyle activities and only focused on MVPA occurring in bouts of ten or more minutes. Therefore, these results may not directly apply to more purposeful PA at higher intensities or physical activities not completed in bouts. Further, accelerometers are known to capture only a portion of PA, for example often excluding PA achieved through swimming, weightlifting, and some biking. Compliant wear was based on the accelerometer, with the assumption that the accelerometer and GPS units were worn concurrently. This assumption was made as the accelerometer and GPS units were on the same belt and there was no need for participants to separate the GPS and accelerometer from the belt. Finally, creation of these PA spaces allows examination of the built environment characteristics in areas where individuals choose to be active. While the built environment characteristics measured from these PA spaces are useful for identifying important characteristics for consideration in intervention studies, they may not be appropriate measures to use as exposures in studies of causal relationships with standard study designs due to biases such as selective daily mobility bias (Chaix et al., 2013).

Overall, this study adds to the growing evidence against using residential buffers to assign built environment exposures without first determining if the residential neighborhood is the appropriate exposure area for the health behavior or factor under consideration. This study suggests that true PA spaces are likely to differ from the residential environment for many people, particularly when the newly proposed individual bout-based definition of PA space is examined. Using other methods such as GPS monitoring or ecological momentary assessment may be more appropriate for assessing the contextual environments in which PA occurs. Future studies examining the locations of other health behaviors in relation to residential buffers may well extend these findings to other disciplines.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.healthplace.2017.03.013.

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