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Authors
Holliday, Katelyn M
Howard, Annie Green
Emch, Michael
et al.

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Where Are Adults Active? An Examination of Physical Activity Locations Using GPS in Five US Cities

Katelyn M. Holliday · Annie Green Howard · Michael Emch · Daniel A. Rodríguez · Wayne D. Rosamond · Kelly R. Evenson

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Abstract Increasing physical activity (PA) at the population level requires appropriately targeting intervention development. Identifying the locations in which participants with various sociodemographic, body weight, and geographic characteristics tend to engage in varying intensities of PA as well as locations these populations underutilize for PA may facilitate this process. A visual location-coding protocol was developed and implemented in Google Fusion Tables and Maps using data from participants (N = 223, age 18–85) in five states. Participants concurrently wore ActiGraph GT1M accelerometers and Qstarz BT-Q1000X GPS units for 3 weeks to identify locations of moderate-to-vigorous (MVPA) or vigorous (VPA) bouts. Cochran-Mantel-Haenzel general association tests examined usage differences by participant characteristics (sex, age, race/ethnicity, education, body mass index (BMI), and recruitment city). Homes and roads encompassed >40% of bout-based PA minutes regardless of PA intensity. Fitness facilities and schools were important for VPA (19 and 12% of bout minutes). Parks were used for 13% of MVPA bout minutes but only 4% of VPA bout minutes. Hispanics, those without a college degree, and overweight/obese participants frequently completed MVPA bouts at home. Older adults often used roads for MVPA bouts. Hispanics, those with ≤high school education, and healthy/overweight participants frequently had MVPA bouts in parks. Applying a new location-coding protocol in a diverse population showed that adult PA locations varied by PA intensity, sociodemographic characteristics, BMI, and geographic location. Although homes, roads, and parks remain important locations for demographically targeted PA interventions, observed usage patterns by participant characteristics may facilitate development of more appropriately targeted interventions.

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K. M. Holliday (✉) · M. Emch · W. D. Rosamond · K. R. Evenson
Department of Epidemiology, University of North Carolina, 137 E. Franklin Street, Suite 306, Chapel Hill, NC 27514, USA
e-mail: khausman@email.unc.edu

A. G. Howard
Department of Biostatistics, University of North Carolina, Chapel Hill, NC, USA

M. Emch
Department of Geography, University of North Carolina, Chapel Hill, NC, USA

D. A. Rodríguez
Department of City and Regional Planning, University of California, Berkeley, CA, USA

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Introduction

Lack of physical activity (PA) is the fourth leading risk factor for mortality globally and accounts for significant disease burden [1]. Despite the numerous benefits of PA, many individuals do not achieve PA recommendations [2, 3]. Over one-third of the world's population has insufficient PA, with proportions varying substantially between countries [4].

Theoretical frameworks suggest that a variety of factors, including individual, social, environmental, and policy, influence behavior [5, 6], yet few studies have examined the specific locational contexts of PA. This information may be important for developing targeted interventions in underactive populations. Researchers have suggested that global positioning system (GPS) technology may facilitate understanding these PA locational contexts [7, 8].

Although a small body of literature examines the locational context of adult PA, several key methodologic issues are apparent in the literature. For example, many studies focused on leisure time PA instead of total PA [9–17] and used self-report PA questionnaires as opposed to objective measures [9–26]. Many studies also solicited a binary yes/no response in regards to use of a particular location type for PA [9–13, 16–25], preventing examination of the percent of PA time completed at a specific location. Studies that did use GPS to aid in location assessment typically lacked specificity of location types, for example by simply reporting the location as inside/outside the home neighborhood [27, 28]. Indeed, lack of specificity of location types is one of the main weaknesses of contemporary automated GIS approaches to examining PA locations, which typically either rely on identifying locations relative to key participant addresses (e.g., within a distance of home, work, or school) or GIS databases that have variable availability and comparability across large study areas.

A device-based study of specific adult PA locations from an expanded geographic scope is notably missing from the literature. This type of study would allow for examination of the locational context of total PA time as well as refinement of location categories. The present study designed a protocol to systematically classify GPS points into PA location types and then implemented it using data from five geographically distinct US cities. Importantly, results are examined by PA intensity, participant sociodemographic characteristics, body mass index (BMI), and geographic characteristics to aid in future development of targeted interventions.

Methods

Study Population

The System for Observing Play and Recreation in Communities (SOPARC) GPS sub-study enrolled participants during spring, summer, and fall from May 2009 to April 2011 in five communities: Los Angeles, California; Albuquerque, New Mexico; Chapel Hill/Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania. Recruitment occurred within key parks in each community as well as from residences located within one mile of these parks. Participants were ineligible if they were <18 years old, non-English speaking, or non-ambulatory. SOPARC conducted sampling to recruit individuals from the age groups in Table 1.

Sociodemographic characteristics (age, sex, race/ethnicity, highest level of education achieved) were collected through questionnaires. Staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height of participants, allowing categorization of BMI into categories of normal weight (<25 kg/m^2), overweight (≥25 to <30 kg/m^2), or obese (≥30 kg/m^2). Further details are available elsewhere [29–31].

Physical Activity Assessment

Participants concurrently wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, FL) accelerometer on the right hip and a Qstarz BT-Q1000X portable GPS unit (weight, 65 g; dimensions, 72 × 46 × 20 mm) on the same belt for three consecutive 1-week periods, both of which collected timestamped data recorded in 1-min epochs. The accelerometer [32] and GPS units [33] performed well in tests of validity.

Accelerometer non-wear was identified as 90 min of consecutive 0 counts, allowing for ≤2 min of nonzero counts if the 30 min before and after the nonzero counts contained no positive counts, and records for these minutes were flagged as non-wear [34]. The GPS data were merged with accelerometer data, including minutes flagged as non-wear, by time stamp.

We examined PA in bouts ≥10 min as recommended by the 2008 PA Guidelines for Americans and the World Health Organization [2, 3] and to facilitate the intensive location-coding protocol. PA bouts were defined as ≥10 min of accelerometer counts occurring above a given cut-point, allowing for 20% of minutes to fall below the cut-point. Analyses were conducted using

Table 1 Participant characteristics in the SOPARC GPS study 2009–2011

	Matthews' MVPA[a]		NHANES MVPA[b]		NHANES VPA[c]	
	N	%	*N*	%	*N*	%
Overall number	223	–	192	–	47	–
Sex						
Male	97	43.5	88	45.8	20	42.6
Female	126	56.5	104	54.2	27	57.4
Age						
18–35	102	45.7	91	47.4	27	57.5
36–59	81	36.3	69	35.9	17	36.2
60–85	40	17.9	32	16.7	3	6.4
Race/ethnicity						
Non-Hispanic White	113	50.7	104	54.2	31	66.0
Non-Hispanic Black	52	23.3	37	19.3	7	14.9
Hispanic	36	16.1	31	16.2	4	8.5
Other	21	9.4	19	9.9	5	10.6
Missing	1	0.4	1	0.5	0	–
Education						
High school /GED or less	48	21.5	35	18.2	3	6.4
Some college or vocational	49	22.0	39	20.3	7	14.9
College or post-grad	126	56.5	118	61.5	37	78.7
BMI						
Healthy weight	77	34.5	74	38.5	21	44.7
Overweight	72	32.3	64	33.3	19	40.4
Obese	74	33.2	54	28.1	7	14.9
Recruitment city						
Los Angeles, CA	47	21.1	45	23.4	10	21.3
Albuquerque, NM	47	21.1	39	20.3	5	10.6
Chapel Hill and Durham, NC	49	22.0	48	25.0	21	44.7
Columbus, OH	40	17.9	28	14.6	5	10.6
Philadelphia, PA	40	17.9	32	16.7	6	12.8
Recruitment location						
Household	46	20.6	44	22.9	8	17.0
Park	175	78.5	146	76.0	39	83.0
Missing	2	0.9	2	1.0	0	–

BMI body mass index, *CA* California, *MVPA* moderate to vigorous physical activity, *NHANES* National Health and Nutrition Examination Survey, *NM* New Mexico, *NC* North Carolina, *OH* Ohio, *PA* Pennsylvania, *VPA* vigorous physical activity

[a] Those who engaged in MVPA bouts (Matthews' definition, ≥760 cpm)

[b] Those who engaged in NHANES MVPA bouts (NHANES definition, ≥2020 cpm)

[c] Those who engaged in NHANES VPA bouts (NHANES definition, ≥5999 cpm)

the Matthews' cut-point [35] (moderate to vigorous PA (MVPA): ≥760 cpm) and the NHANES cut-points [36] (MVPA: ≥2020 cpm; vigorous PA (VPA): ≥5999 cpm). A bout began and ended with a PA minute and could contain no more than four consecutive minutes below the cut-point. Four 10-h days were considered compliant [37]; however, a sensitivity analysis using at least 12, 10-h days was completed given recent GPS monitoring recommendations based on this population [38].

Location Assessment

GPS units had Wide Area Augmentation System (WAAS) enabled to improve accuracy and points with <1-min epochs were removed. A protocol for visually classifying GPS points into PA location types was developed (Appendix 1). The protocol was piloted on a subset of data by multiple coders to qualitatively examine reliability and improve clarity. Protocol changes included addition of categories, clarification of the role of PA bouts in making coding decisions, and refinement of the rules for identifying points involved in motorized travel. The final protocol was implemented by a single author (KMH).

Participant home addresses were geocoded and compared with nighttime GPS data to impute missing home addresses and validate geocoded addresses, similar to previous studies [39]. Then, Google Fusion Tables (Google Inc., Mountain View, CA) was used to map PA bouts within 35 miles of the participant's home address, resulting in a study area ~19,000 mi^2 across the five cities. Google Maps features like satellite and historical street view were used to categorize GPS points into a variety of mutually exclusive PA location types via visual inspection, including participant homes, roads, parks, commercial locations (stand-alone retail locations, strip malls, malls, dense commercial districts, restaurants, and gas stations), schools (including pre-K to university), fitness locations (pay gyms, private tennis/soccer facilities, swim clubs, dance/martial arts studios), footpaths/trails, and residential locations (excluding the participant's home). The remaining location types were collapsed into an "other" category for analysis due to low frequency; however, they were coded as services (banks, hotels, post offices, healthcare facilities, libraries), offices, golf courses, factories, places of worship, and entertainment (non-fitness oriented; e.g., museums, zoos). Points located in dense downtown areas that were too difficult to classify were coded as "downtown" and grouped with "other." The protocol called for consideration of the overall pattern of points within a PA bout when coding but did not require all points within the same bout to receive the same code. For example, if a participant walked to a park and then completed PA in the park, he/she could have minutes classified as road and park within the same bout. Finally, because GPS accuracy is often limited indoors, the protocol allowed for imputation of some missing GPS points by examining the recorded point(s) before and after the missing point(s), as has been done in other studies of PA involving GPS [40]. This protocol was approved by the *Institutional Review Board of the University of North Carolina.*

Statistical Analysis

In order to compare location use across sociodemographic groups known to participate in widely different volumes of PA (e.g., older adults vs younger adults), the percent of PA bout time spent in each location was calculated overall and by sociodemographic characteristics, BMI categories, and geographic characteristics for all three cut-points of PA bouts. Sociodemographic characteristics examined include sex, age category, race/ethnicity, and education. Geographic characteristics were recruitment state and recruitment site (park vs household). Differences by these characteristics were examined using Cochran-Mantel-Haenzel tests for general association. Results are focused on three location types (homes, roads, and parks) that may be most appropriate for intervention targeting.

Results

Thirteen of the 248 enrolled participants were excluded due to missing data (two missing all accelerometer data and 11 missing all GPS data) leaving 235 participants. Of these, 224 had at least four 10-h days of compliant accelerometer wear [median (IQR) = 17 (13–20) days] and 223, 192, and 47 completed bouts of Matthews' MVPA, NHANES MVPA, or NHANES VPA, respectively, on days with at least 10 h/day of wear (Table 1).

Participant Sociodemographic Characteristics

More females than males participated and most were recruited from parks as opposed to households (Table 1). Although most participants were younger, white, and college educated, other groups were represented in moderate proportions (Table 1). Participants with Matthews' MVPA bouts were evenly distributed among categories of BMI. Patterns of sociodemographic characteristics were similar across enrolled participants and those with Matthews' and NHANES MVPA; however, those with NHANES VPA bouts were more educated ($p = 0.01$), had a lower BMI category ($p = 0.05$), and were more likely to be

Table 2 Total, median per participant, and percent of Matthews' MVPA, NHANES MVPA, and NHANES VPA bout minutes spent in each location type among SOPARC GPS sub-study participants over 3 weeks, 2009–2011

	Matthews' MVPA[a]			NHANES MVPA[b]			NHANES VPA[c]		
	Bout minutes			Bout minutes			Bout minutes		
	Total	Median/participant (IQR)	%	Total	Median/participant (IQR)	%	Total	Median/participant (IQR)	%
Home	42,735	116 (40, 242)	29.4	9447	6 (0, 43)	20.3	994	0 (0, 0)	17.8
Road	21,885	25 (0, 105)	15.1	12,820	6 (0, 48)	27.6	1250	0 (0, 0)	23.6
Park	19,465	11 (0, 72)	13.4	5808	0 (0, 12)	12.5	227	0 (0, 0)	4.3
Commercial	12,375	14 (0, 42)	8.5	1573	0 (0, 3)	3.4	206	0 (0, 0)	3.9
School	11,064	0 (0, 32)	7.6	4242	0 (0, 0)	9.1	634	0 (0, 0)	12.0
Other	7408	0 (0, 23)	5.1	1665	0 (0, 0)	3.6	74	0 (0, 0)	1.4
Fitness	6092	0 (0, 0)	4.2	3565	0 (0, 0)	7.7	1023	0 (0, 0)	19.3
Residential	5053	0 (0, 17)	3.5	1009	0 (0, 0)	2.2	112	0 (0, 0)	2.1
Footpath/trail	2016	0 (0, 1)	1.4	1352	0 (0, 0)	2.9	478	0 (0, 0)	9.0
Motorized[d]	147	0 (0, 0)	0.1	75	0 (0, 0)	0.2	14	0 (0, 0)	0.3
Missing	16,989	5 (0, 59)	11.7	4943	0 (0, 3)	10.6	331	0 (0, 0)	6.3
Total minutes		145,229			46,499			5293	
Median (range) bout duration		16 (10–197)			20 (10–147)			26 (10–112)	

IQR interquartile range, *MVPA* moderate to vigorous physical activity, *NHANES* National Health and Nutrition Examination Survey, *VPA* vigorous physical activity

[a] MVPA bout minutes defined by Matthews' definition (≥760 cpm)

[b] MVPA bout minutes defined by NHANES definition (≥2020 cpm)

[c] VPA bout minutes defined by NHANES definition (≥5999 cpm)

[d] Motorized denotes minutes spent in short motorized travel during a PA bout (i.e., these minutes fell below the active threshold but were still part of a PA bout)

recruited from North Carolina ($p = 0.02$) as compared with those having Matthews' MVPA bouts (Table 1).

Time Spent in Physical Activity Intensities

Time spent in PA bouts varied by PA intensity (Table 2). Overall, 223 participants (99.6% of those with compliant wear) contributed 145,229 min in Matthews' MVPA bouts, 192 (85.7% of those with compliant wear) contributed 46,499 min in NHANES MVPA bouts, and 47 (21.0% of those with compliant wear) contributed 5293 min in NHANES VPA bouts on days with at least 10 h of accelerometer wear over the 3 weeks (Table 2).

PA Locations

The most common location for PA in Matthews' MVPA bouts was the participant's home (29.4% of bout minutes), whereas roads were most common for the higher cut-point NHANES MVPA and VPA (27.6 and 23.6% of bout minutes, respectively; Table 2). Together, homes and roads accounted for over 40% of bout-based PA minutes across all three PA intensities. Fitness facilities and schools were also important locations for NHANES VPA bouts (19.3 and 12.0% of VPA bout minutes, respectively; Table 2). Parks were the locations for 13.4% of Matthews' MVPA bout minutes and 12.5% of NHANES MVPA bout minutes but only 4.3% of NHANES VPA bout minutes (Table 2).

PA Locations by Participant Sociodemographic and Study Characteristics

Cochran-Mantel-Haenzel analyses suggested a general association between PA location types and all sociodemographic characteristics, BMI categories, and geographic characteristics (sex, age, race/ethnicity, BMI, education, recruitment city, and location) for each intensity of PA ($p < 0.0001$). However, the number of participants with VPA minutes was low in many stratified analyses (Tables S1–S8).

Participant homes were common locations for PA of all intensities, but usage differed by sociodemographic characteristics, BMI categories, and geographic characteristics (Tables 2 and 3). For lower cut-point Matthews' MVPA, homes were used for more PA bout minutes by females (35.0% of bout minutes vs 23.3% for males; Table 3 and Table/Fig. S1) and participants recruited from New Mexico and Ohio (38.6 and 35.6% of bout minutes vs 18.7% for California and 23.3% for Pennsylvania; Table 3 and Table/Fig. S6). For the higher cut-point NHANES MVPA, homes were most used by Hispanics (29.1% of bout minutes vs e.g. 18.8% for Non-Hispanic Whites; Table 3 and Table/Fig. S3), those

Table 3 Percent of MVPA bout minutes spent in three location types by sociodemographic characteristics of participants in the SOPARC GPS study 2009–2011

	Matthews' MVPA[a]				NHANES MVPA[b]			
	Minutes	Home	Road	Park	Minutes	Home	Road	Park
Sex								
Male	69,706	23.3	14.6	15.8	22,610	20.3	27.6	16.6
Female	75,523	35.0	15.5	11.2	23,889	20.3	27.6	8.6
Age								
18–35	60,699	26.7	14.5	9.2	22,920	19.3	23.2	12.7
36–59	56,124	31.4	12.7	15.2	14,801	21.5	25.7	14.6
60–85	28,406	31.3	21.1	18.8	8778	21.1	42.3	8.4
Race/ethnicity								
NH White	84,745	30.9	16.5	13.8	27,604	18.8	30.7	11.2
NH Black	25,671	27.6	8.3	14.6	6945	22.5	16.9	12.0
Hispanic	20,433	28.2	13.6	12.6	5858	29.1	24.9	22.6
Other	14,183	25.2	20.8	9.9	6030	15.6	28.3	9.5
Education								
≤High School	24,265	32.3	11.3	12.0	6366	28.3	16.6	22.5
Some college or vocational	26,646	28.5	10.5	16.4	5301	28.5	19.1	6.1
College or post-grad	94,318	28.9	17.3	12.9	34,832	17.6	30.9	11.6
BMI								
Healthy weight	64,603	29.2	16.6	17.7	20,523	13.4	30.3	15.1
Overweight	49,080	28.3	15.9	13.7	16,842	25.7	30.4	13.3
Obese	31,546	31.7	10.8	4.1	9134	25.9	16.3	5.2
City								
Los Angeles, CA	32,532	18.7	36.0	16.4	12,644	2.9	60.8	20.6
Albuquerque, NM	29,592	38.6	7.2	19.1	6964	50.5	12.0	7.6
Chapel Hill/Durham, NC	41,545	31.7	13.1	16.0	12,951	11.8	24.6	13.9
Columbus, OH	18,993	35.6	2.9	4.3	6103	37.0	2.8	6.2
Philadelphia, PA	22,567	23.3	9.2	4.6	7837	22.7	11.9	6.4
Recruitment								
Household	24,886	28.5	20.7	6.5	8354	18.1	34.9	11.9
Park	117,242	29.3	14.2	13.9	37,732	20.2	26.2	12.6

BMI body mass index, *CA* California, *MVPA* moderate to vigorous physical activity, *NH* non-Hispanic, *NHANES* National Health and Nutrition Examination Survey, *NM* New Mexico, *NC* North Carolina, *OH* Ohio, *PA* Pennsylvania

[a] Matthews' definition, ≥760 cpm

[b] NHANES definition, ≥2020 cpm

with less education (28.3% ≤high school education and 28.5% some college vs 17.6% for college degree; Table 3 and Table/Fig. S4), overweight or obese participants (26% of bout minutes vs 13% for healthy weight; Table 3 and Table/Fig. S5), and those recruited from New Mexico and Ohio (50.5 and 37.0% of bout minutes vs 2.9% for California and 11.8% for North Carolina; Table 3 and Table/Fig. S6). Homes were used most for the highest cut-point NHANES VPA by males (27.0% of bout minutes vs 9.4% for females; Table/Fig. S1) and overweight participants (25.5% of bout minutes vs 6.4% for healthy weight participants; Table/Fig. S5).

Roads were commonly used for PA of all intensities, particularly for higher cut-point NHANES MVPA and VPA (Table 2). For the lowest cut-point Matthews' MVPA, roads were most used by older adults (21.1% of bout minutes for those aged 60–85 vs 14.5% for those aged 18–35 and 12.7% for those aged 36–59; Table 3 and Table/Fig. S2) and participants recruited from California (36% of bout minutes vs ≤13% for participants recruited from all other sites; Table 3 and Table/Fig. S6). For NHANES MVPA, roads were again important for older adults (42.3% of bout minutes for those aged 60–85 years vs 23.2% for those aged 18–35 and 25.7% for those aged 36–59 years; Table 3 and Table/Fig. S2) and participants recruited from California (61% of bout minutes vs 25% for North Carolina and <12% for those recruited from other locations; Table 3 and Table/Fig. S6) and additionally for some race/ethnic groups (e.g., 30.7% of bout minutes for non-Hispanic whites vs 16.9% for non-Hispanic blacks) and those with higher education (30.9% of bout minutes for those with ≥ college education vs 16.6% for ≤high school education and 19.1% for some college or vocational; Table 3 and Table/Fig. S4). For NHANES VPA, females (31.8% of bout minutes vs 14.8% for males; Table/Fig. S1), those with higher education, and healthy weight and overweight individuals frequently used roads for the highest cut-point NHANES VPA. Those with a college or postgraduate education spent 29.4% of NHANES VPA bout minutes on roads, those with a healthy weight 29.6% of minutes, and overweight individuals 24.2% (Tables/Figs. S4/S5). However, there were few individuals with NHANES VPA who have less than a college education or who are obese.

Parks contributed to Matthews' and NHANES MVPA more than NHANES VPA (Table 2). Race/ethnic groups had similar patterns of park use for Matthews' MVPA (non-Hispanic Black 14.6% of bout minutes, Hispanic 12.6%, non-Hispanic White 13.8%, other 9.9%) (Table 3 and Table/Fig. S3). The distribution of Matthews' MVPA bout minutes in parks was also similar across those recruited from California, North Carolina, and New Mexico (16.4, 16.0, 19.1%) but less for those recruited from Ohio and Pennsylvania (4.3 and 4.6%) (Table 3 and Table/Fig. S6). Park use increased with age (9.2% of bout minutes for ages 18–35, 15.2% for ages 36–59, 18.8% for ages 60–85) (Table 3 and Table/Fig. S2) was greater for healthy and overweight participants (17.7 and 13.7% of bout minutes vs 4.1% for obese; Table 3 and Table/Fig. S5) and was slightly higher among those recruited from parks (13.9% of bout minutes) as compared with those recruited from nearby houses (6.5% of bout minutes, Table 3 and Table/Fig. S7). For NHANES MVPA, males (16.6% of bout minutes vs 8.6% for females; Table 3 and Table/Fig. S1), Hispanics (22.6% of bout minutes vs ≤12% for other race/ethnic groups; Table 3 and Table/Fig. S3), those with the least education (22.5% of bout minutes for ≤high school vs 6.1% for some college and 11.6% for ≥college degree; Table 3 and Table/Fig. S4), healthy and overweight participants (15.1 and 13.3% vs 5.2% for obese; Table 3 and Table/Fig. S5) as well as those recruited from California and North Carolina (20.6 and 13.9% vs <8% for those recruited from other sites; Table 3 and Table/Fig. S6) used parks for more of their bout minutes. In addition, 12.6% of NHANES MVPA bout minutes were in parks for those recruited from parks versus a similar 11.9% for those recruited from nearby households (Table 3 and Table/Fig. S7). At the highest cut-point NHANES VPA, males (7.5% of bout minutes vs 1.3% for females; Table/Fig. S1) and overweight individuals (10.7 vs 1.3% for healthy weight; Table/Fig. S5) had more of their bout minutes in parks.

Sensitivity analyses restricting to participants with at least 12 10-h days of wear reduced sample sizes, particularly for Matthews' and NHANES MVPA. However, this change showed little effect on the distribution of PA bout time across the various locations (Table S8).

Discussion

Using a newly developed location-coding protocol, this study found that adult PA locations varied by PA intensity as well as participant sociodemographic characteristics, BMI categories, and geographic characteristics.

These patterns can inform targeted intervention development, both by identifying locations typically used by some populations and potentially underused by others. Interventions developed by relying on the PA location use patterns observed herein should then be tested to examine effectiveness. While several PA location types were identified, participant homes, roads, and parks were common locations where individually and community-targeted interventions are possible, although patterns by which participant groups used these locations varied. These locations may therefore benefit consideration when implementing Community Preventative Services Task Force (CPSTF)-recommended PA interventions, which are based on systematic reviews of the PA intervention literature [41]. Importantly, some recommended CPSTF interventions are at the community level, targeting potential population level effects.

The CPSTF recommends individually adapted health behavior change programs to increase PA [41]. These programs assist individuals with incorporating PA into daily routine, so they may be especially beneficial for groups like overweight/obese individuals, Hispanics, and those with lower education who appear to gain much of their PA at home. Due to social pressures, overweight and obese individuals may be more comfortable undertaking higher cut-point MVPA at home [42]. Likewise, groups that experience health disparities like Hispanics and those with lower educational levels may have less access or less time to participate in PA outside the home environment. At the same time, PA in the home was common for nearly all groups in comparison with other locations, which agrees with previous research on adults [10, 14–17, 20, 21, 26]. Therefore, use of individually adapted health behavior change programs focused on the home environment may aid in increasing PA for a wide variety of individuals.

Another CPSTF-recommended intervention focuses on community- and street-scale urban design and land use policies [41]. This study and previous research on adults [9–11, 18, 21–25] suggest that roads and footpaths/trails are important PA locations, particularly higher cut-point NHANES MVPA and VPA. Thus, they may be important locations for these urban design and land use policy interventions, such as those proposed by the National Complete Streets Coalition, especially in areas where road or footpath/trail use is low. For example, participants recruited from California in this study used roads for far more of their PA than did participants from other states across all PA intensities. This suggests that factors like the built environment or weather may make roads in the Los Angeles area more supportive of PA than in other sites, meaning they may be a prime target for intervention in areas where they are underutilized for PA.

The CPSTF also recommends social support interventions in communities, which help individuals develop social networks of PA partners [41]. The results of the present study imply that social support interventions could focus on creating walking or running groups for younger adults, those with less education, and obese individuals. These groups used roads for NHANES MVPA half as much as their older, higher educated, and lower weight counterparts, suggesting they may underutilize roads.

Parks are often thought of as natural locations in which to focus community level PA interventions such as those described by CPSTF. Although parks have been identified as popular locations for adult PA [9–12, 18–26], few studies have described park use as a proportion of total PA [29]. In this study, parks appeared to be more important for Matthews' and NHANES MVPA than VPA. This suggests that CPSTF-recommended interventions like social support interventions in communities, community-wide campaigns, and creation of or enhanced access to places for PA combined with information outreach activities could focus on teaching community members ways to engage in VPA in parks. This could entail developing new park programming or better advertising current programming. It may also involve considering structural modifications or enhancements at parks to better reach all users.

This study demonstrates that some groups known to have low PA do use parks. For example, more Matthews' MVPA occurred in parks with increasing age and those with a high school education or less used parks more for NHANES MVPA than did other groups. Importantly, Matthews' MVPA park use was similar across race and education categories and Hispanics used parks for NHANES MVPA more than other groups, indicating the potential ability of park interventions to support PA without exacerbating existing health disparities. At the same time, obese individuals used parks less for MVPA than did their normal and overweight counterparts, indicating a potential group that would benefit from targeted park-related interventions.

Park use was more prominent among participants recruited from the California, New Mexico, and North Carolina sites than from the Ohio and Pennsylvania sites. This was unexpected given that attempts were made to control for season by excluding monitoring in winter. However, park use could differ due to weather within season or non-seasonal attributes of the sites such as park amenities, quality, and safety, which are unaccounted for in this study.

Most recent studies of the locational context of PA focus on identifying PA locations relative to key participant addresses (e.g., within a distance of home, work, or school) [43], use GIS databases that, while useful and informative for single-city studies, have variable availability and comparability for multi-city studies [44, 45], or rely on self-reported destinations [46, 47]. Further, most current studies ultimately include an “other” category to capture locations that fall outside of predefined location categories without regard to the proportion of PA that may occur in these alternative locations [43, 44]. Therefore, a recent framework for studying PA locations indicated that the field would be improved by methods that increase specificity and accuracy of the context in which PA occurs and suggests that solely focusing on PA near home and work is not representative of all PA environments [48]. The protocol used in this study is a significant departure from recent work assessing PA locations using GIS. It provides instructions for precisely classifying locations of PA regardless of their proximity to home or work addresses and can be consistently implemented across geographically varying study locations that have inconsistent GIS data availability. Further, although a small proportion (~5%) of locations were reported as “other” in this study, these locations were precisely coded initially and only collapsed for presentation purposes once they were identified as uncommon locations. In addition, the protocol provides instructions for capturing more detailed information about the PA locations used (e.g., the park amenity used, the presence of sidewalks or bike lanes along the road segment used, the type of school and school amenity used). Therefore, the proposed protocol is highly adaptable to differing geographic locations and PA behavior patterns of participants and can inform a variety of PA location-related study questions.

Limitations

Although this is a large sample of geographically and sociodemographically diverse participants among studies of physical activity, it is not a representative sample. Thus, results based on sociodemographic or geographic characteristics may not be representative of these groups. Further, expected selection of those participating in VPA was observed, with most being younger, white, highly educated, and non-obese. Therefore, stratified analyses must be viewed with caution due to the small number of participants represented in some categories. Several participant characteristics correlated with recruitment state, making geographic and sociodemographic patterns difficult to disentangle, and two sites (Ohio and Pennsylvania) had lower GPS compliance resulting in greater missing data at these sites. Nevertheless, this is a large study of diverse participants incorporating detailed examination of PA locations with a protocol that could be implemented within more representative populations.

Cochran-Mantel-Haenzel analyses suggested significant differences in PA location type by PA intensity, sociodemographic characteristics, BMI categories, and geographic characteristics, but multinomial modeling accounting for correlation of minute by minute PA location within participants was not possible due to the computational burden associated with modeling at the minute level. Additionally, although the coding protocol was implemented by a single coder to ensure consistency of interpretation, quantitative examination of reliability across multiple coders was not possible due to the time-intensive nature of the protocol.

The standard definition for PA intensities used in this study is not based on age or BMI, suggesting that the small number of seniors and obese individuals with VPA may be an underestimate of true VPA in these populations [49]. In addition, the accelerometers used are known to capture only a proportion of PA, for example they fail to capture swimming and some bicycling and weightlifting, although these activities are uncommon in the general population.

Finally, while the sociodemographic patterns of PA location use identified are useful for developing 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 [50]. Instead, they provide starting points for development of interventions that can then be tested for causal effects.

Conclusion

This study provides a new location-coding protocol for classifying PA locations more precisely than previous studies. Application of this protocol in a sociodemographically and geographically diverse adult population suggests that common PA locations vary by PA intensity and participant sociodemographic and geographic characteristics. Homes, roads, and parks were discussed as potential PA locations when implementing CPSTF interventions. Each of these locations had sociodemographic- and geographic-specific use patterns that may be important when developing targeted interventions capable of increasing PA at the population level.

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Compliance of Ethical Standards

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