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ORIGINAL ARTICLE

Locations of Joint Physical Activity in Parent–Child Pairs Based on Accelerometer and GPS Monitoring

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Abstract

Background Parental factors may play an important role in influencing children's physical activity levels.

Purpose This cross-sectional study sought to describe the locations of joint physical activity among parents and children.

Methods Parent–child pairs (N=291) wore an Actigraph GT2M accelerometer and GlobalSat BT-335 global positioning systems (GPS) device over the same 7-day period. Children were ages 8–14 years. Joint behavior was defined by a linear separation distance of less than 50 m between parent and child. Land use classifications were assigned to GPS datapoints.

Results Joint physical activity was spread across residential locations (35 %), and commercial venues (24 %), and open spaces/parks (20 %). Obese children and parents performed less joint physical activity in open spaces/parks than under/normal weight children and parents (ps<0.01).

Conclusions Understanding where joint parent–child physical activity naturally occurs may inform location-based interventions to promote these behaviors.

Keywords Moderate to vigorous physical activity · Sedentary behavior · Parents · Children · Global positioning systems · Environments

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Introduction

Evidence suggests that parental factors may play an important role in influencing children's physical activity levels [1, 2]. Parents may help promote children's physical activity by providing support, purchasing equipment, paying fees, providing transportation, watching and supervising activities, offering encouragement, and discussing benefits [3, 4]. Evidence is less consistent about whether parents' physical activity levels influence the amount of physical activity that their children perform [1, 5–7]. Research in this area typically does not distinguish between parents' physical activity, performed *separately from* versus *together with* their children. Recent work suggests that only a small proportion of parents' overall physical activity is done with their children [8, 9]. Increasing joint parent–child physical activity could provide opportunities for positive parental role modeling of active behaviors while health benefits for children and parents alike. Information about the locations where parents and children engage in joint physical activity can inform location-based programs and policies to promote joint physical activity in parents and children [10, 11].

A growing body of research uses new methods such as global positioning systems (GPS) and ecological momentary assessment to investigate the locations of children's physical activity. Studies have found that most of children's moderate-to-vigorous intensity physical activity occurs at school and at home [12–14]. Research has shown that only small amounts (approximately 2–10 %) of children's physical activity takes place in parks and green spaces [13–17]. Fewer studies have examined where adults' physical activity takes place. Troped et al. [18] found that most of adults' moderate-to-vigorous physical activity took place more than 1 km from home. Time use data suggest that more of adults' sports and exercise occur outdoors (25 %) and at home (25 %) than at a gym/health club (8 %) or at work (3 %)

[19]. However, no known studies to date have sought to identify the locations of physical activity that parents and children perform together.

This study examined the locations of joint physical activity and sedentary behavior in parent–child pairs who wore an accelerometer and GPS device over the same 7-day period. The first objective was to classify the locations of (a) joint parent–child moderate-to-vigorous physical activity (MVPA), (b) joint parent–child sedentary behavior, (c) child MVPA accompanied by parent sedentary behavior, and (d) parent MVPA accompanied by child sedentary behavior according to primary land use type (e.g., residential, commercial, and open space). Evidence suggests that overweight and obese children and adults may have different patterns, types, and locations of physical activity than their normal-weight counterparts [17, 20, 21]. Thus, our second objective was to determine whether weight status of the parent and child are associated with the location of joint activity for each joint behavior type. Based on prior work [17], we hypothesized that overweight and obese children and parents would perform more joint physical activity in residential locations than open space and parks.

Methods

Sample

This study used data from a subgroup of children and parents enrolled in a 4-year project examining the effects of smart growth community design on family obesity risk. Participants included a convenience sample of fourth through eighth grade children (ages 8–14 years) and their parents. Families lived in Chino, CA, USA or surrounding communities within 30 min driving time from Chino. The city of Chino is located within the greater Los Angeles Basin, about 35 miles east of downtown Los Angeles. According to the 2010 US Census, Chino has a population of 77,983 persons with a population density of 2,630 people per square mile. About 50 % of residents are of Latino or Hispanic origin. The median annual household income is $71,000 [22]. Participants were recruited through informational flyer, posters, and letters. All recruitment materials included the study recruitment hotline phone number and email address. A telephone recruiter called all interested families and screened for eligibility. Inclusion criteria consisted of the following: (a) child currently enrolled in grades 4–8, (b) living in Chino, CA, USA or a surrounding community, and (c) annual household income less than $210,000. Extremely high income households were excluded because the goal of the study was to focus on children from families who have elevated obesity risk. Parents and children who met the eligibility criteria were scheduled for a data collection appointment at a local community site or their home. Written informed consent and minor assent was obtained from participants. This research was reviewed and approved by the Institutional Review Board at the University of Southern California and the Committee on the Protection of Human Subjects, University of California, Berkeley.

Study Design

Baseline data from the 4-year study were used. Data were collected from March 2009–December 2010. No data collection took place from late July–August and during January due to typically adverse temperatures and weather conditions that limit outside activity in that part of Southern California. Within the parent–child pairs, both wore an accelerometer and GPS device over the same 7-day period.

Measures

Physical Activity

Physical activity was assessed using an Actigraph, Inc. GT2M model activity monitor (firmware v06.02.00), although only data from the vertical axis were utilized. Participants wore the device on the right hip attached to an adjustable belt for seven continuous days. The devices were not worn when sleeping, bathing, or swimming. Activity counts were recorded in 30-s epochs in both parents and children to facilitate matching among the pairs. Cutpoints for moderate-to-vigorous physical activity MVPA were applied from studies of national surveillance data [23, 24]. For adults, the MVPA threshold was 2,020 counts per minute (equivalent to 3 metabolic equivalents (METs)). MVPA for children was defined using age-specific thresholds generated from the Freedson prediction equation [25, 26]. A threshold for moderate activity of 4 METs was used for children (as opposed to a 3 METs moderate activity cutoff for adults) to account for higher resting energy expenditure in children and youth [27, 28]. For children and adults, sedentary activity was defined as less than 100 counts per minute [29, 30].

Location Monitoring

Geographic locations were recorded through portable GPS devices worn by both children and parents. Data were gathered for a 7-day period with the BT-335 Bluetooth GPS data logger device by GlobalSat Technology Corp (Taipei) attached to a belt worn around the waist along with the accelerometer. The BT-335 (16 M bit, 1,575.42 MHz) consists of a GPS receiver and data logger with bluetooth PC interface. This device records time, date, speed, altitude, and

GPS location at preset intervals. It is Wide Area Augmentation System enabled and uses a SiRF star III chipset for accurate position tracking (up to 3 m accuracy outdoors) and improved indoor signal acquisition. The recording interval was set to a 30-s epoch to match the accelerometer specifications. A battery charger was provided and participants were instructed to recharge the battery each night. After the GPS devices were returned, all recorded information was downloaded to a computer where the recorded longitudinal and latitudinal data and speed were downloaded to a CSV file format. Linear distance between the parent and child for each 30-s epoch was calculated using geographic coordinates from the GPS. The GPS devices and accelerometers were marked with separate color-coded stickers for the parent and child to avoid any mistaken cross usage.

Land Use Classifications

GPS datapoints for joint parent–child behavior (at the level of the 30-s epoch) were given land use classification in a geographic information system (GIS) using a Southern California Association of Governments (SCAG) database [31]. Datapoints were assigned the land use classification of the area nearest to the point that had land use data. Most of the GPS datapoints (93.7 %) fell in an area that had been classified in the SCAG database. However, some GPS datapoints had small distances to their nearest land use classified area (6 % had distances >0 but <15 m). GPS datapoints that were greater than 50 m away from the nearest area that had a classification were excluded from the analyses (0.08 %). For analyses, land uses were grouped into six major categories: residential (e.g., houses, apartments and condos), commercial (e.g., retail, restaurants, office use, and manufacturing), open space (e.g., vacant lots, parks, golf courses, gardens, and beaches), educational (e.g., schools and school grounds), public facilities (e.g., community centers, churches, and libraries), and other (e.g., military, mixed uses, airports, freeways, roads, and utilities).

Height and Weight

Parents' and children's height and weight were measured in duplicate using an electronically calibrated digital scale (Tanita WB-110A) and professional stadiometer (PE-AIM-101) to the nearest 0.1 kg and 0.1 cm, respectively. Body mass index (BMI) was calculated (kilogram per square meter). Parents' weight status was classified using the following BMI categories: under or normal weight (BMI<25), overweight (BMI=25–29.9), and obese (BMI≥30). Children's weight status was classified according to CDC age- and sex-specific BMI percentile cutoffs (under or normal weight, <85th percentile; overweight=85th to less than the 95th percentile; obese, ≥95th percentile).

Demographic Variables

Age, sex, and ethnicity were assessed through child and parent self-report surveys. Ethnicity was coded as Hispanic versus non-Hispanic. Parents reported annual household income, which was divided into quartiles (≤$30,000. $30,001–60,000, $60,001–100,000, and >$100,000).

Data Merging and Processing

Accelerometer and GPS files were imported into the R version 2.9.2 programming language interface. Date and time stamps to the nearest 30-s epoch were used to match all accelerometer and GPS records within each parent–child pair. In the numerous cases where concurrent accelerometer and GPS were unavailable for either the parent or the child, we used a missing data code (NA) for designating the accelerometer or GPS values for these epochs. Overnight (11 PM–5 AM) and school (8 AM–3 PM on weekdays during the school season) hours were removed from the analyses. Strings of consecutive readings of 0 activity counts lasting 60 min or more were considered accelerometer non-wear and excluded from analyses. Activity outliers were identified as records with greater than 16,383 counts per 30-s epoch [32]. Motorized activity was also excluded from the analyses, which were identified by records with speeds greater than 32 kph since typical bicycling speeds range from 15 to 30 kph (9.32–18.64 mph). Once these records were removed, parent–child pairs were determined to have sufficient data for inclusion in the analysis if they had a minimum of two valid days (any combination of weekdays or weekend days) of matched data—where a valid weekday was defined as having a minimum of 2 h of matched accelerometer and GPS datapoints for the pair (between 3 PM and 11 PM), and a valid weekend day was defined as having a minimum of 4 h of matched accelerometer and GPS datapoints for the pair (between 5 AM and 11 PM). "Joint" behaviors were defined as behaviors that occurred at the same time and in the same location (<50 m apart). A maximum separation of <50 m between the parent and child was selected because this distance is approximately equivalent to the length of a ball court (e.g., basketball, volleyball, racquetball) or large residential yard. The joint behavior occurred inside of the pair's residential neighborhood was defined as the GPS coordinates falling within a 500-m buffer around the home address. Four types of joint parent–child behavior were examined: (a) joint MVPA, (b) joint sedentary behavior, (c) child MVPA accompanied by parent sedentary behavior, and (d) parent MVPA accompanied by child sedentary behavior.

Data Analyses

Two multilevel multinomial logistic regression models were fit for each of the four types of joint parent–child behavior to predict the likelihood of occurring in each land use type as compared with residential locations (reference group). The first model tested the effect of child weight status (i.e., BMI category). The second model tested the effect of parent weight status (i.e., BMI category). Each of the four types of joint behavior (joint MVPA, child MVPA/parent sedentary behavior, parent MVPA/child sedentary behavior, joint sedentary behavior) was tested in a separate model. The level of analysis was the 30-s epoch. Only pairs with at least 1 min (two 30-s epochs) of the joint behavior were included in each model. Models testing the effect of child weight status controlled for child age, sex, ethnicity (Hispanic versus non-Hispanic) and annual household income. Models testing the effects of parent weight status controlled for parent age, sex, ethnicity (Hispanic versus non-Hispanic), and annual household income. Predicted margins (i.e., standardized predicted probabilities adjusting for all of the other model covariates) were calculated using the multinomial logistic regressions [33]. All models used the generalized estimation equation model-fitting method to adjust standard errors for the clustering of observations within each parent–child pair. We only interpreted weight status differences for land use categories where at least 5 % of the joint behavior occurred for both weight status groups, as categories with <5 % of the behavior would have little clinical or policy relevance. All analyses were conducted using SUDAAN 10.0 (RTI International, Research Triangle Park, NC, USA).

Table 1 Demographic characteristics for parent–child pairs with sufficient data (N=291)

	Child *n* (%)	Parent *n* (%)
Sex		
Female	152 (52.2)	255 (87.6)
Male	139 (47.8)	36 (12.4)
Age (mean, range)	11.2 (8–14)	39.6 (26–62)
BMI category		
Under/normal weight	186 (63.9)	79 (27.2)
Overweight	45 (15.5)	120 (41.2)
Obese	60 (20.6)	92 (31.6)
Race (*n*, %)		
Caucasian/White	76 (26.1)	
African American/Black	11 (3.8)	
Hispanic	125 (43.0)	
Asian	27 (9.3)	
Other	52 (17.9)	
Annual household income ($)		
≤30,000		73 (26.5)
30,001–60,000		61 (22.1)
60,001–100,000		82 (29.7)
>100,000		60 (21.7)

Sample sizes vary due to missing data

BMI body mass index

Results

Descriptive Statistics

A total of 1,023 parent–child pairs responded to the recruitment materials of which 667 pairs were reached for eligibility screening. Among those who were screened, 447 pairs met eligibility criteria of which 407 pairs were further consented to participate in the study. From this group, 387 pairs completed the baseline data collection of which 363 pairs provided some accelerometer and GPS data. Among these pairs, 291 had a sufficient amount of matched accelerometer and GPS data to be included in the data analyses. Demographic characteristics for parent–child pairs with sufficient data are shown in Table 1 (N=291). Children were 52.2 % female and 43.0 % Hispanic. The distribution of children's weight status was as follows: 63.9 % under or normal weight, 15.5 % overweight, 20.6 % obese. The majority of parents participating in this study were female (87.6 %) with a mean age around 40.0 years (SD=6.0 years, range=26–62 years). Parents' weight status was as follows: 27.2 % under or normal weight, 41.2 % overweight, 31.6 % obese. About one quarter of the households in the sample earned ≤$30,000 annually. Parent–child pairs, who were excluded due to insufficient GPS and accelerometer data differed from the analytic sample on a few factors. Parents in the excluded sample were younger and more likely to be male than parents in the analytic sample (ps<0.05). Children from pairs excluded due to insufficient data had a higher mean BMI percentile than the analytic sample ($p<0.05$).

On average, parent–child pairs had 4.5 (SD=1.6) valid days of matched accelerometer-GPS data over the 7-day period (M=310.8 min, SD=75.2 min per day)—after removing records representing overnight hours (11 PM–5 AM), school time (8 AM–3 PM on weekdays), time spent in motorized transit (>32 kph), missing accelerometer and GPS data and outliers, and accelerometer nonwear for either the parent or the child. Information about missing, outlying, and nonwear data for the GPS and accelerometer are reported elsewhere [8]. Missing GPS data (due to power loss or signal loss) and accelerometer nonwear accounted for the majority of the unavailable data.

Children performed an average of 19.5 min (SD=15.5) of total MVPA and 170.7 min (SD=53.53) of total sedentary behavior each day during nonschool waking hours. Parents engaged in 11.7 min (SD=11.7 min) of total MVPA and 191.0 min (SD=55.5 min) of total sedentary behavior.

Parent–child pairs spent an average of 233.6 min (SD=80.0) per day in the same location (less than 50 m apart) during nonschool waking hours together, not accounting for time spent together in the car. Of that time, parents and children spent 2.4 min (SD=4.1, median=0.9) per day performing MVPA together and 92.9 min (SD=40.1, median=89.3) per day engaging in sedentary behavior together during nonschool, waking hours. Parents performed 7.4 min (SD=7.2, median=5.3) per day of sedentary behavior while their child was engaging in MVPA nearby (<50 m). Conversely, children engaged in 1.9 min (SD=2.3, median=1.1) per day of sedentary behavior while their parent was performing MVPA nearby (<50 m).

Of the 291 parent–child pairs in the analytic sample, 229 pairs (79 %) had at least 1 min of joint MVPA (6,566 joint MVPA epochs across the entire analytic sample), 273 pairs (94 %) had at least 1 min of child MVPA accompanied by parent sedentary behavior (14,433 total epochs across the entire sample), 279 pairs (96 %) had at least 1 min of parent MVPA accompanied by child sedentary behavior (4,681 total epochs across the entire sample), and all of them had at least 1 min of joint sedentary behavior (2,465,559 total epochs across the entire sample). These values represent the sizes of the subsamples analyzed in the current paper. Other descriptive information about joint parent–child behaviors observed in this study is reported elsewhere [8].

Locations of Joint Parent–Child Behaviors

Figure 1 shows the proportion of joint MVPA, child MVPA accompanied by parent sedentary behavior, parent MVPA accompanied by child sedentary behavior, and joint sedentary behavior occurring in each land use type during nonschool waking hours. The largest proportion of joint parent–child MVPA occurred in residential locations (35 %), followed by commercial land uses (e.g., retail stores, restaurants, personal services, private health club/gym, and motels; 24 %), open space (e.g., parks, gardens, and wildlife preserves; 20 %), educational institutions (e.g., schools; 14 %), public facilities (e.g., government, health care, religious, libraries, and community centers; 7 %), and mixed/other land uses (e.g., roads and water; 1 %). Figure 2 shows an example of a parent and child performing MVPA together at a location classified as open space. When joint parent–child MVPA occurred in an open space, 35 % of these instances took place within the pair's neighborhood and 65 % occurred outside of their neighborhood. The proportion of joint parent–child MVPA occurring within the neighborhood was even less for commercial (17 %), educational (13 %), and public facility (10 %) settings. During nonschool waking hours, the majority of child MVPA accompanied by parent sedentary behavior, parent MVPA accompanied by child sedentary behavior, and joint sedentary behavior occurred in residential locations (~75 %), with smaller proportions taking place in the other land use categories. Open spaces served as the location for 13 % of child MVPA accompanied by parent sedentary behavior, 10 % of parent MVPA accompanied by child sedentary behavior, and 8 % of joint sedentary behavior during nonschool waking hours.

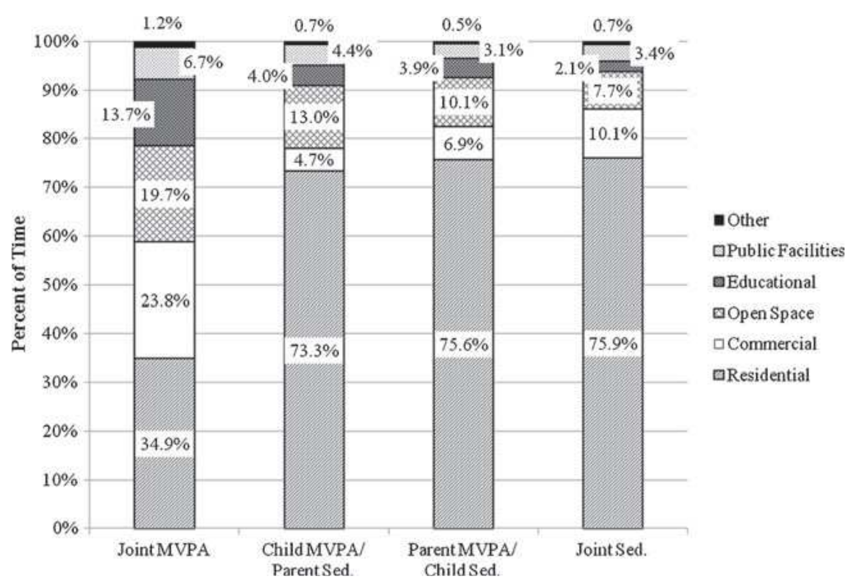

Fig. 1 Joint parent–child behaviors during nonschool waking hours by land use categories. The *x*-axis indicates the types of joint parent–child behavior. The *y*-axis indicates the percent of time the joint behavior occurred in each land use category. Land use categories were as follows: residential (e.g., houses, apartments, and condos), commercial (e.g., retail, restaurants, office use, and manufacturing), open space (e.g., vacant lots, parks, golf courses, gardens, and beaches), educational (e.g., schools and school grounds), facilities (e.g., community centers, churches, and libraries), and other (e.g., military, mixed uses, airports, freeways, roads, and utilities). Joint behavior was defined by a linear separation distance of less than 50 m between the parent and child. *MVPA* moderate-to-vigorous physical activity, *Sed.* sedentary behavior

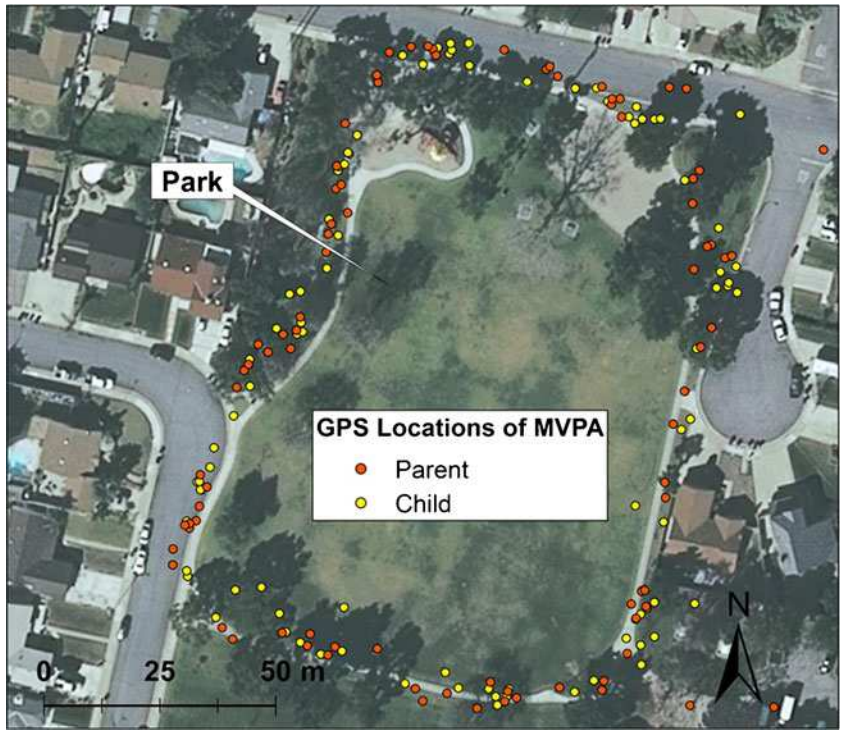

Fig. 2 Geovisualization of global positioning system (GPS) monitoring points for a parent–child pair show joint MVPA occurring within a land use categorized as open space. Joint behavior was defined by a linear separation distance of less than 50 m between the parent and child

Locations of Joint Behaviors by Child Weight Status

Table 2 shows that after adjusting child age, sex, Hispanic origin, and annual household income, the locations of joint parent–child MVPA differed by child weight status (adjusted Wald F=3.45, df=10, p<0.01). As compared with children who were under/normal weight and overweight, obese children were less likely to perform joint MVPA with their parent on land classified as open space than in residential locations (see Fig. 3). Differences in the land use type of parent MVPA accompanied by child sedentary behavior were by child weight status were also observed (adjusted Wald F=2.79, df=10, p<0.01). However, this difference occurred in educational settings versus residential locations and education settings accounted for less than 5 % of parent MVPA/child sedentary behavior for normal weight, overweight, and obese children. The locations of child MVPA accompanied by parent sedentary behavior and joint sedentary behavior during nonschool waking hours did not differ by child weight status.

Locations of Joint Behaviors by Parent Weight Status

Table 3 show that the locations of joint parent–child MVPA differed by parent weight status (adjusted Wald F=3.27, df=10, p<0.01) after adjusting parent age, sex, Hispanic origin, and annual household income. As compared with parents who were under and normal weight, overweight and obese parents were less likely to perform joint MVPA with their child on land classified as open space as compared with residential settings (see Fig. 4). Differences in the land use type of child MVPA accompanied by parent sedentary behavior were also observed by child weight status (adjusted Wald F=2.20, df=10, p<0.05). However, these differences occurred in commercial and other settings versus residential locations and commercial and other settings each represented less than 5 % of child MVPA/parent sedentary behavior for normal weight, overweight, and obese parents. The locations of parent MVPA accompanied by child sedentary behavior and joint sedentary behavior during nonschool waking hours did not differ by parent weight status.

Discussion

The study represents one of the first attempts to use objective measures (GPS and accelerometer) to understand where children and their parents engage in physical activity and sedentary behavior together during nonschool waking hours. Results indicated that joint parent–child physical activity occurred fairly evenly across residential locations, open spaces/parks, and commercial venues. The majority of the open spaces/parks and commercial venues used for joint parent–child MVPA were outside of the pair's immediate neighborhood. In contrast, the vast majority of joint parent–child sedentary behavior occurred in residential settings. Instances where child MVPA was accompanied by parent sedentary behavior and parent MVPA was accompanied by child sedentary behavior was also more likely in residential locations with the former more likely than the latter to take

Table 2 Results of multinomial logistic regression predicting land use type for joint parent–child behaviors during non-school waking hours by child BMI categories (odds ratio, 95 % CI)

Covariate	Commercial	Open space	Educational	Public facilities	Other	Adjusted Wald *F*
Joint MVPA						
Child BMI category						3.45*
Under/Normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	1.49 (0.75–2.98)	0.88 (0.36–2.15)	0.84 (0.18–4.00)	1.25 (0.51–3.03)	1.11 (0.25–4.87)	
Obese	2.57 (1.16–5.72)	0.43 (0.18–1.02)	3.37 (1.49–7.62)	4.05 (1.39–11.79)	0.49 (0.05–4.66)	
Child MVPA/parent sedentary behavior						
Child BMI category						1.76
Under/normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	0.78 (0.40–1.53)	1.17 (0.50–2.78)	0.90 (0.30–2.67)	0.72 (0.25–2.07)	0.10 (0.01–1.01)	
Obese	0.48 (0.20–1.16)	0.91 (0.42–2.00)	0.49 (0.16–1.53)	1.99 (0.89–4.46)	2.46 (0.50–12.15)	
Parent MVPA/child sedentary behavior						
Child BMI category						2.79*
Under/normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	0.49 (0.20–1.22)	2.48 (0.79–7.85)	0.32 (0.08–1.26)	1.30 (0.36–4.71)	1.88 (0.28–12.71)	
Obese	1.18 (0.41–3.41)	1.17 (0.32–4.33)	0.12 (0.03–0.43)	1.65 (0.59–4.55)	6.47 (0.57–73.66)	
Joint						
Child BMI category						1.01
Under/normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	1.21 (0.80–1.83)	1.55 (0.61–3.95)	0.61 (0.21–1.79)	0.89 (0.49–1.61)	0.52 (0.18–1.55)	
Obese	0.97 (0.59–1.59)	0.59 (0.20–1.77)	0.39 (0.15–1.01)	0.99 (0.53–1.86)	2.31 (0.45–11.77)	

The unit of analysis was the 30-s epoch. All models controlled for child age, sex, ethnicity (Hispanic vs. non-Hispanic), and annual household income. Reference group for land use categories=residential (e.g., houses, apartments, and condos). Land use categories were as follows: commercial (e.g., retail, restaurants, office use, and manufacturing), open space (e.g., vacant lots, parks, golf courses, gardens, and beaches), educational (e.g., schools and school grounds), facilities (e.g., community centers, churches, and libraries), and other (e.g., military, mixed uses, airports, freeways, roads, and utilities). Joint behavior was defined by a linear separation distance of less than 50 m between the parent and child

MVPA moderate-to-vigorous physical activity

*$p<0.01$

place in open spaces/parks. The locations of joint parent–child behavior showed some differences by weight status.

Results indicating that open spaces and parks offered a common setting for joint physical activity performed by parents and children add to a growing body of literature highlighting the importance of these types of settings for providing physical activity opportunities [34–36]. Previous studies examining children's total physical activity have found smaller percentages to take place in parks and green spaces (only 2–10 %) [13–17] than the percentage of child's physical activity with a parent occurring in open spaces in the current study (almost 20 %). A possible explanation is that parks and open spaces provide more opportunities for physical activities involving both children and their parents (e.g., playing catch, sports, bicycling), whereas joint parent–child physical activities may be restricted in other settings (e.g., health clubs, dance, or karate studios), which may offer primarily single-age group classes and activities. Other research suggests that children with greater access to parks during childhood have lower BMI when they reach age 18 [37]. Interestingly, results from the current study indicate that a notable amount of sedentary behavior occurs in parks and open spaces. On average during nonschool waking hours, parents and children engaged in 8 min of joint sedentary behavior per day in open spaces and parks. There was also about 1–2 min per day, on average, when children were physically active at a park or open space with a sedentary parent nearby. If both of these instances of parental sedentary behavior at a park or open space were converted to physical activity, parents could obtain an additional hour or so more of physical activity per week, which would account for over a third of the total recommended amount [38].

The likelihood of joint parent–child physical activity taking place at parks or other types of open space, however, varied by child and parent weight status. As hypothesized, normal and underweight children and parents were more likely to engage in joint physical activity at a parent at parks or open space than obese children and adults. In contrast, obese children and parents, engaged in a greater percentage of their joint physical activities on school grounds, public facilities (including community centers and churches), and

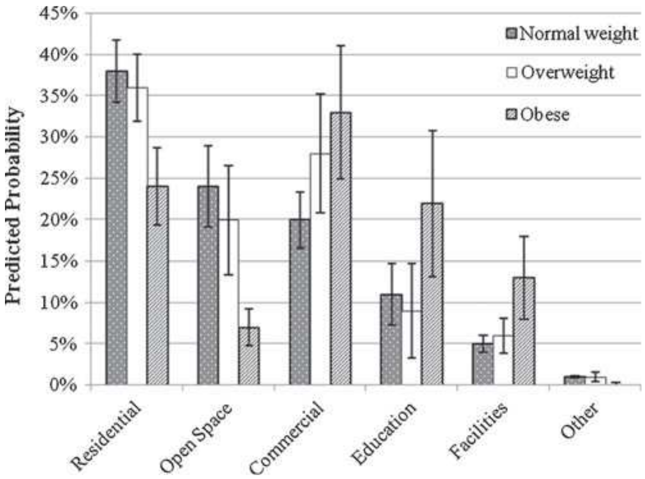

Fig. 3 Predicted probability of joint parent–child MVPA during non-school waking hours in different land use categories by children's body mass index (BMI) category. Land use categories were as follows: residential (e.g., houses, apartments, and condos), commercial (e.g., retail, restaurants, office use, and manufacturing), open space (e.g., vacant lots, parks, golf courses, gardens, and beaches), educational (e.g., schools and school grounds), facilities (e.g., community centers, churches, and libraries), and other (e.g., military, mixed uses, airports, freeways, roads, and utilities). *Error bars on the graph* represent standard errors. Joint behavior was defined by a linear separation distance of less than 50 m between the parent and child

commercial locations (including retail stores and restaurants). In a previously published paper reporting results for this same study sample, the average number of joint parent–child physical MVPA minutes per day did not differ by parent or child weight status [8]. Also, post hoc analyses of interactions by joint parent–child physical activity level found that among parent–child pairs who engaged in more than 2.0 min per day of joint MVPA, those pairs comprised of normal weight performed a greater percentage of joint MVPA at parks and open space (32 %) than pairs comprised of obese parents (7 %; $p=0.051$). These results suggest that the manner but not the amount of joint parent–child physical activity differs between weight groups. Normal and overweight parents and children may accumulate their joint physical activity through recreational sports and exercise performed at parks, beaches, or other open spaces. Obese parents and children, on the other hand, may perform more of their joint physical activity through walking behaviors, possibly due to the fact that other types of exercise are perceived as too strenuous. In fact, a recent study found that obese individuals performed almost half of their moderate intensity activity through lower intensity, longer duration walking [21]. Walking activities performed together by obese children and parents (whether for recreational or transportation purposes) may be more likely to

Table 3 Results of multinomial logistic regression predicting land use type for joint parent–child behaviors during non-school, waking hours by parent BMI categories (odds ratio, 95 % CI)

Covariate	Commercial	Open space	Educational	Public facilities	Other	Adjusted Wald *F*
Joint MVPA						
Parent BMI category						3.27**
Under/normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	0.99 (0.46–2.14)	0.55 (0.24–1.24)	1.27 (0.44–3.64)	1.91 (0.62–5.88)	0.33 (0.06–1.84)	
Obese	1.64 (0.69–3.88)	0.28 (0.12–0.64)	3.79 (1.41–10.23)	2.34 (0.51–10.78)	0.77 (0.07–8.11)	
Child MVPA/parent sedentary behavior						
Parent BMI category						2.20*
Under/normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	0.62 (0.29–1.32)	0.69 (0.33–1.42)	0.61 (0.24–1.58)	1.07 (0.41–2.80)	0.08 (0.01–0.53)	
Obese	0.37 (0.15–0.95)	1.05 (0.42–2.63)	0.38 (0.13–1.12)	1.81 (0.65–5.07)	1.95 (0.33–11.46)	
Joint sedentary behavior						
Parent BMI category						1.02
Under/normal weight	1.00	1.00	1.00	1.00	1.00	
Overweight	1.17 (0.77–1.79)	1.11 (0.44–2.81)	1.11 (0.46–2.67)	0.95 (0.53–1.72)	0.28 (0.10–0.78)	
Obese	0.92 (0.60–1.40)	0.85 (0.31–2.29)	0.89 (0.30–2.67)	0.74 (0.35–1.55)	1.38 (0.39–4.87)	

The unit of analysis was the 30-s epoch. All models controlled for parent age, sex, ethnicity (Hispanic vs. non-Hispanic), and annual household income. Reference group for land use categories=residential (e.g., houses, apartments, and condos). Land use categories were as follows: residential (e.g., houses, apartments, and condos), commercial (e.g., retail, restaurants, office use, and manufacturing), open space (e.g., vacant lots, parks, golf courses, gardens, and beaches), educational (e.g., schools and school grounds), facilities (e.g., community centers, churches, and libraries), and other (e.g., military, mixed uses, airports, freeways, roads, and utilities). Joint behavior was defined by a linear separation distance of less than 50 m between the parent and child. Results for the model predicting the land use type for parent MVPA/child sedentary are not presented because the *p* value was approaching 0 due to singularities in data

*$p<0.05$

**$p<0.01$

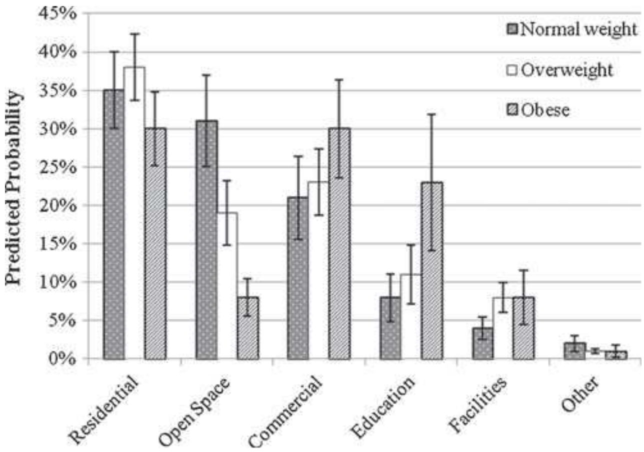

Fig. 4 Predicted probability of joint parent–child MVPA during non-school waking hours in different land use categories by parents' body mass index (BMI) category. Land use categories were as follows: residential (e.g., houses, apartments, and condos), commercial (e.g., retail, restaurants, office use, and manufacturing), open space (e.g., vacant lots, parks, golf courses, gardens, and beaches), educational (e.g., schools and school grounds), facilities (e.g., community centers, churches, and libraries), and other (e.g., military, mixed uses, airports, freeways, roads, and utilities). *Error bars on the graph* represent standard errors. Joint behavior was defined by a linear separation distance of less than 50 m between the parent and child

occur in residential, commercial, public, and educational land use types than parks and open space. Regardless, there may be reasons to encourage obese parents and children to engage in more joint parent–child physical activity at parks and open spaces. Primarily, evidence suggests that physical activity occurring in green spaces is more enjoyable [39, 40] and has a greater likelihood of reaching moderate-to-vigorous intensity [32] than activity occurring elsewhere. Therefore, encouraging park-based joint physical activity for obese children may offer health benefits in the long term by supporting the maintenance of higher energy expending activities.

Despite the use of objective physical activity and location measures, this study has a few limitations. It should be noted that there was an imbalance in the proportion of mothers (88 %) versus fathers (12 %) comprising the parent–child pair. Thus, father–child physical activity and sedentary behavior is underrepresented. The accelerometer and GPS technology have inherent weaknesses. The GPS units have differential measurement error depending on available satellites, meteorology, and physical obstructions, with errors often less than 5 m, but also frequently much larger (i.e., >15 m), which could have caused over- or underestimation of joint activity when the linear distance of parent–child proximity was close to the specific 50 m. GPS measurement error could also have resulted in misclassification of land use types when the individual was near the border separating two different land use parcels. Also, a greater amount of measurement error and missing data is expected with indoor compared to outdoor wear, although the SiRF star III chipset is designed to improve the performance of the GPS device in indoor environments. Rates of data loss were similar to rates observed in other studies using accelerometer [41, 42] and GPS devices [43–45]. However, the number of missing analysis units was compounded by the deletion of matched parent–child minutes when either accelerometer or GPS observations were missing in either the parent or the child. While there is some evidence to suggest that 2 days is a reliable indicator of MVPA [24, 46], whether 2 days offers a reliable indicator of joint physical activity and sedentary behavior is unknown. Statistical analyses adjusted for the clustering of observations within parent–child pairs, which is important as these observations are likely to be correlated. The analyses, however, did not adjust for spatial autocorrelation because we expect observations closer together in space to have an increased likelihood of the same land use type. Furthermore, the methodology for land use classification may not accurately represent active transportation or recreational trips. The land use of joint behaviors taking place on sidewalks or roads could be misclassified as the use category of the adjacent land parcel (e.g., commercial and educational) instead of the other category, which includes roads. Also, we were unable to control for potential differences in park access because many of the participants lived in a new community for which complete park GIS data are not yet available. Furthermore, data were not available on the nature of the social interactions between parents and children during joint physical activity and sedentary behavior (e.g., interacting behavior versus parallel but non-interacting behavior). Lastly, joint behaviors performed by pairs with younger, male parents and children with a higher BMI may not be fully represented because they were more likely to be excluded due to insufficient data. Also, results may not be generalizable to urban populations, since the data were primarily captured in suburban and exurban communities.

Parks and other types of open spaces may offer opportunities for unstructured joint parent–child physical activity, which may be restricted in other settings such as organized classes and lessons. The lower likelihood of parks and open spaces to serve as locations for joint parent–child physical activity among obese parents and children highlights an area for future investigation and intervention. Whether land use patterns for joint parent–child activity represent preferences for types of activities or amenities should be the focus of further research.

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