



Use of global positioning system for physical activity research in youth: ESPAÇOS Adolescentes, Brazil



Claudia Oliveira Alberico^{a,b,c,d,*}, Jasper Schipperijn^e, Rodrigo S Reis^{a,b,f}

^a Graduate Program in Physical Education, Federal University of Parana, Rua Coracao de Maria, 92 Curitiba, Parana, Brazil

^b Research Group in Physical Activity and Quality of Life (GPAQ), Pontifical Catholic University of Parana, Rua Imaculada Conceicao, 1155 Curitiba, Brazil

^c Center for Geospatial Analytics, College of Natural Resources, North Carolina State University, 2820 Faucette Drive, 27695 Raleigh, NC, United States

^d Department of Parks, Recreation and Tourism Management, North Carolina State University, 2820 Faucette Drive, 27695 Raleigh, NC, United States

^e Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Campusvej 55, 5230 Odense, Denmark

^f Prevention Research Center, Brown School, Washington University in St. Louis, One Brookings Drive, Campus Box, 1196 St. Louis, United States

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ABSTRACT

The built environment is an important factor associated with physical activity and sedentary behavior (SB) during adolescence. This study presents the methods for objective assessment of context-specific moderate to vigorous physical activity (MVPA) and SB, as well as describes results from the first project using such methodology in adolescents from a developing country. An initial sample of 381 adolescents was recruited from 32 census tracts in Curitiba, Brazil (2013); 80 had their homes geocoded and wore accelerometer and GPS devices for seven days. Four domains were defined as important contexts: home, school, transport and leisure. The majority of participants ($n = 80$) were boys (46; 57.5%), with a normal BMI (52; 65.0%) and a mean age (SD) of 14.5 (5.5) years. Adolescents spent most of their time at home, engaging in SB. Overall, the largest proportion of MVPA was while in transport (17.1% of time spent in this context) and SB while in leisure (188.6 min per day). Participants engaged in MVPA for a median of 28.7 (IQR 18.2–43.2) and 17.9 (IQR 9.2–32.1) minutes during week and weekend days, respectively. Participants spent most of their day in the leisure and home domains. The use of Geographic Information System (GIS), Global Positioning System (GPS) and accelerometer data allowed objective identification of the amount of time spent in MVPA and SB in four different domains. Though the combination of objective measures is still an emerging methodology, this is a promising and feasible approach to understanding interactions between people and their environments in developing countries.

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1. Background

Youth obesity is a growing concern in public health (Burdette and Whitaker, 2005; Martín et al., 2012; Oreskovic et al., 2015) and physical activity (PA) is a relevant strategy to improve health. Nonetheless, only two out of ten adolescents worldwide achieve the recommended levels of moderate to vigorous intensity (MVPA) (Guidelines, 2008; Hallal et al., 2012). Improving policies and environments aiming to include PA as part of daily life could potentially reverse the pandemic of physical inactivity (Kohl et al., 2012; Reis et al., 2016).

The built environment has been associated with PA and sedentary behavior (SB) of adolescents (Baumann et al., 2012; Owen et al., 2009; Reis et al., 2009). Environmental attributes and characteristics such as availability of and access to parks (Bedimo-rung et al., 2005; Kaczynski et al., 2008; Sallis, 2009), higher street connectivity,

availability and quality of sidewalks, lower levels of crime safety (Ding et al., 2011; Xu et al., 2010), and availability of equipment for PA engagement in schools (Harrison et al., 2014; Knuth, 2012; Wechsler et al., 2000) have been found to be associated with higher levels of PA. However, nearly all evidence in this field emerged from high-income countries and few from upper middle-income countries (Ding et al., 2016; Hallal et al., 2012; Patton et al., 2012), where violence and early pregnancy, among other factors, are the main concerns for adolescent health (WHO, 2016).

Although the built environment might be assessed through direct and indirect methods (Hino and Reis, 2010), combining methods and tools has been a recommended approach to increase precision and variability (Brownson et al., 2009; Hino et al., 2012; Kerr et al., 2013). Several studies have documented greater sensitivity to assess variations in environmental attributes, PA and SB when objective measures are applied (Ding et al., 2011; Ferreira et al., 2007; Klinker et al., 2014a, 2014b), particularly the Geographic Information System (GIS) (Rodríguez et al., 2005). However, GIS use is limited by data availability (Thornton et al., 2011) and when data are available, they don't provide

* Corresponding author at: 2820 Faucette Drive, 27695 Raleigh, NC, United States.

E-mail addresses: coalberi@ncsu.edu (C.O. Alberico), jschipperijn@health.sdu.dk (J. Schipperijn), reis.rodriigo@wustl.edu (R.S. Reis).

contextual information (e.g. interactions between people and space). These limitations have been partially addressed by combining GIS with GPS (Global Positioning System) devices, allowing researchers to capture and merge objective environment characteristics with real time information on where people are within a specific location (e.g. within a park) or route (e.g. to or from school), which may substantially improve precision and variation on environment, PA and SB information (Jankowska et al., 2014; Klinker et al., 2014a; Schipperijn et al., 2014).

To the best of our knowledge, there is no evidence emerging from the peer-reviewed literature showing results from studies conducted in developing countries. To date, the limited available evidence comes from developed countries located in North America (Almanza et al., 2012; Dunton et al., 2014; Ellis et al., 2014; Kerr et al., 2012; Lee and Li, 2014), Europe (Audrey et al., 2014; Chaix et al., 2013; Cooper et al., 2010a, 2010b; Klinker et al., 2014a; Klinker et al., 2014b; Madsen et al., 2014; Wheeler et al., 2010) and Oceania (Duncan et al., 2010, 2009; Quigg et al., 2010).

We wanted to assess if using combined GPS, accelerometer and GIS data was feasible in developing countries where the availability of high quality GIS data is typically lower, and participant reaction to being monitored by GPS could be more negative. Therefore, this paper: 1) presents the methods for data collection using GPS units and assessment of context-specific PA and SB, and 2) describes results applying this methodology in Brazilian adolescents, through Projeto ESPAÇOS Adolescentes.

2. Methods

The International Physical Activity and Environment Network (IPEN) Adolescent Study (Hino et al., 2012; Kerr et al., 2013) aims for a standard study design and set of measures taken across different countries in different continents in order to compare the relation between PA and environment throughout them. In Brazil, to increase acceptance by the community, the study was named “Projeto ESPAÇOS Adolescentes” (ESPAÇOS = SPACES, in English), and was thoroughly publicized in the city of Curitiba, Southern Brazil. With a population of over 1.85 million inhabitants in 2013, Curitiba is internationally recognized for its urban planning characteristics such as many green areas and effective public transportation (Moyses et al., 2004; Reis et al., 2010). This study was approved by the Ethics Committee of the Pontifical Catholic University of Parana (136.945,10/24/2012).

2.1. Location selection and participant recruitment

Walkability and area income of all 2125 census tracts (CT) available in the city of Curitiba at the time of this study were identified (mean area = 0.21 km²) through a standardized walkability index (Frank et al., 2010; Kerr et al., 2013). All CT were ranked according to deciles based on the normalized walkability index and household-level income. The lowest and highest deciles were cross-compared to classify CT into four groups: high walkability–high income; high walkability–low income; low walkability–high income; low walkability–low income (Grow et al., 2008; Hino et al., 2012). Within each walkability and income group eight CT were randomly selected ($n = 32$).

All households within the selected 32 CT were visited aiming to identify eligible participants. A second round of visits took place on a different day and time to try to reach any possible residents who might not have been at home during the first attempt. Adolescents from 12 to 17 years old, without any permanent physical or cognitive restrictions, enrolled at an educational institution and residing for at least one year within the selected CTs were eligible for the study. A parent or someone who lived in the same residence and was over the age of 18 was invited to participate as well, and a date and time were set for the first visit and handing out of the equipment.

2.2. Data collection

On the date and time scheduled by the recruiter, a researcher arrived at the home of the participant with a family form, written consent forms (parent and adolescent), a questionnaire (parent), an accelerometer and a GPS tracker unit (adolescent). The questionnaire was administered to a parent through face-to-face interviews and the devices were handed to the adolescents along with a diary to be filled out daily. Instructions were given to the participants on how to use the devices. All possible phone numbers were recorded on the family form, along with three dates and times the adolescent would be available to answer phone calls or text messages, to improve quality of data and compliance. Also, an appointment was scheduled for the return of equipment and an interview with the adolescent. Control calls were made on every second and fifth day during the use of the devices, as well as the day before the second visit to remind the participants of their appointment. During the second visit the diary was thoroughly scanned by the researcher in order to add any information that could be useful for validating data. On this visit, the adolescent was interviewed, and waist circumference, height and weight were measured.

2.3. Measurements (physical activity, locations, diary, anthropometry and questionnaire are all within measurements)

2.3.1. Physical activity

Assessment of objective physical activity was achieved using tri-axial Actigraph GT3X and GT3X + activity monitors, during seven consecutive days. Devices were programmed to start recording at 30 Hz from the day after the delivery of the equipment. Data were downloaded using ActiLife 6.8.0 software and scanned to identify any technical problems.

2.4. Locations

QStarz BT-1000× and BT-1000XT GPS units were used to record the locations of all participants, during the same seven days as the activity monitor. Devices were setup to record every 15 s. The “log” button, used to turn the device on for data collection, was secured with black tape in the ‘on’ position so participants would not have access to it. The units were sent out with discharged battery and would start working the moment the participant charged the device for the first time, the same night of the interview, so it could be used the next day. Initializing the devices and downloading of data were done using QTravel 1.46 software. Files were scanned for possible errors after download.

All GPS devices underwent calibration procedures to assure correct measurement and proper satellite reception. Tests included: battery life, where devices are charged to full battery and observed for total time until the battery is dead; cold and warm start, to provide information on finding a fix at first starting and after continuous use; static validity, to observe accuracy using a geodetic point; and dynamic validity, to observe accuracy when with interference of buildings and moving (Kerr et al., 2011).

2.5. Diary

Participants were asked to fill out a diary during the week they wore the equipment. Questions included time of start and end of wearing the belt, school attendance, physical education classes and recess times. Also, they were asked to list all leisure physical activities, including location and time.

2.6. Anthropometry

Body mass index (BMI) was calculated using objectively measured weight and height. A digital scale (WISO, model W721 with an infrared sensor), was used to measure both weight and height at the end of the

second visit to the participants' homes. A tape was used to measure waist circumference and all researchers went through extensive training for standardization of measures with both pieces of equipment. BMI calculations were transformed to an age adjusted z-score using a validated procedure (Cole et al., 2000).

2.7. Questionnaire

Trained interviewers administered the questionnaires. Both parent and adolescent surveys included questions on the community and neighborhood environment, physical activity and socio-demographics. For parents, questions included their own information and the adolescent's behaviors. For the adolescents, questions included psychosocial correlates for physical activity (e.g. self-efficacy, social support), sedentary behavior, occupation and school information. Social economic status was assessed based on the number of items within the household (ABEP, 2013) and parental schooling years.

2.8. Data processing

The web-based Personal Activity and Location Measurement System (PALMS) was used for processing and combining PA (accelerometer) and location (GPS) data (see ucsd-palms-project.wikispaces.com). Files were aggregated to 15-s epochs and continuous periods of 60 min of zero values were classified as accelerometer non-wear time. Location and PA data were combined based on timestamps of each data point. Additionally, accelerometer data was classified in intensity levels using validated cut points (Evenson et al., 2008) for youth physical activity (in counts per minutes, sedentary: ≤ 100 ; moderate to vigorous activity: ≥ 2296) (Trost et al., 2011). It is important to note that “sedentary” is being used as a PA threshold and not sedentary behavior, as defined by the Sedentary Behavior Network, as waking activities of ≤ 1.5 METs, performed while sitting or reclining (Network, 2012).

The PALMS parameters for filtering, trip detection, and trip mode detection were set based on validated settings (Carlson et al., 2014). Invalid GPS points were identified by looking at unrealistically high speeds (> 150 km/h) or extreme changes in distance (> 1000 m) and elevation (> 100 m) between epochs. Trips were identified and categorized into

vehicle (> 35 km/h), biking (> 10 km/h and < 35 km/h) and walking (< 10 km/h).

A PALMS data set was imported into a purpose-built PostgreSQL database and joined with all diary information and location data from GIS in order to identify context-specific measures. Fig. 1 displays the data-flow and methodology applied. Each epoch was assigned to a domain based on a decision tree, with definitions for each domain. Once a point was assigned to a domain, it was excluded from being assigned to other domain; i.e. the domains were mutually exclusive.

The theoretical model SLOTH (sleep, leisure, occupation, transport and home) was used to guide the categorization in the leisure, school, transport and home domains (Baumann et al., 2012; Pratt et al., 2004). Points were considered ‘home’ if they were found within the participant's home parcel and up to 10 m from the limits of the parcel, defined in GIS. School was defined similar to the home domain, using geocoded school's parcels. All epochs that PALMS recognized as part of a trip were included in the transport domain and, finally, all remaining points were classified as free time/leisure.

2.9. Analyses

SPSS 17.0 and Excel 2013 were used to identify participants with valid data, determined by one valid weekday of ten hours or one weekend day of eight hours (Klinker et al., 2014a, 2014b). All participants with no time spent at home or school were further investigated to determine whether they spent time in a secondary home and went to school on that day. All valid days were retained and individual means were calculated. Furthermore, days were stratified into week and weekend days as the contexts can't be compared. Descriptive statistics were calculated using frequency distributions (frequency (n), and relative frequency (%)), mean and range, or median and interquartile range (IQR) for non-normally distributed variables.

3. Results

In total, 432 families were invited to participate in the study. Of those, 42 (9.7%) dropped out during the study and another nine (2.0%) were excluded due to issues such as wrong telephone number or failure to find someone at home. All adolescents were invited to wear both devices, and there were no other criteria to do so. Five

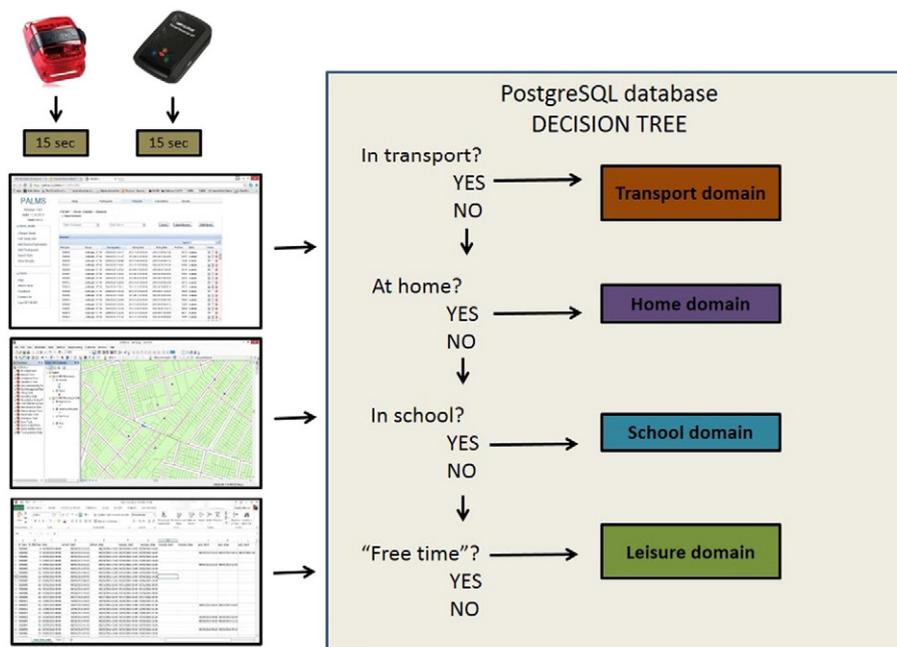


Fig. 1. Decision tree used to assign epochs to domains (Curitiba, Brazil, 2013).

Table 1

Demographic characteristics of all participants, participants who wore GPS and participants with valid GPS data (Curitiba, Brazil, 2013).

	All participants	Participants wearing GPS	Participants with valid GPS data	X ²	p
Demographic characteristics	n = 381 100%	n = 147 38.6%	n = 80 11.8%		
Gender, boys, n (%)	180 (47.2)	71 (48.3)	46 (57.5)	1.88	>0.05
Age, years, mean (standard deviation)	14.7 (6.2)	14.5 (6.0)	14.5 (5.5)	1.84	>0.05
BMI, normal, n (%)	265 (69.6)	95 (64.6)	52 (65.0)	1.92	>0.05
Social economic status, intermediate, n (%)	184 (48.3) ^a	71 (55.0) ^b	42 (58.3) ^c	1.91	>0.05
Parental gender, women, n (%)	314 (83.3) ^d	120 (82.2) ^e	63 (79.8) ^e	1.90	>0.05
Parental education status, high school, n (%)	138 (36.6) ^d	60 (41.1) ^e	32 (40.5) ^e	1.87	>0.05

^a Missing n = 50.^b Missing n = 18.^c Missing n = 8.^d Missing n = 4.^e Missing n = 1.

participants (1.3%) refused to wear GPS devices. From a total of 381 adolescents, only 147 (38.6%) were able to wear both the accelerometer and GPS due to the limited number of devices available (35 units). After deployment of GPS units, 67 (44.9%) adolescents were excluded as no data was recorded or showed incomplete satellite information, leading to a final count of 80 adolescents with complete and valid GPS and accelerometer data.

The final and analytical sample included mostly boys (46; 57.5%), with a mean age of 14.5 years old and normal BMI (52; 65.0%) (Table 1). Overall, 58.3% presented intermediate social economic status, most parents participating in the study were women (63; 79.8%) and 40.5% had high school education. There were no differences in gender, age, BMI, SES, parental gender and education distributions between the total recruited sample (n = 381) and the analytical sample (n = 80) (p > 0.05). Median daily accelerometer wear time in minutes was 830.7 (IQR 714.6–939.8) for all participants wearing GPS and 733.33 (IQR 538.3–835.4) for those participants with valid GPS data. Mean number of valid weekdays was 2.0 (range 0–7) and 3.7 (range 2–5) and weekend days were 0.7 (range 0–3) and 1.3 (range 0–2), for all GPS wearers and valid respondents, respectively (Table 2).

Table 3 shows the median time accumulated in the four domains, showing patterns of total wear time, moderate to vigorous physical activity (MVPA) and sedentary behavior (SB), spent in specific contexts in week or weekend days. During weekdays, participants spent most of the time in the leisure domain (305.0 min), followed by home (247.4 min), transport (36.2 min) and school (92.6 min) domains. On weekends, adolescents also spent most time in the leisure domain (288.8 min), followed by home (261.1 min) and transport (40.2 min). No time was spent in the school domain during weekend days.

During weekdays, MVPA (8.5 min) occurred in the leisure domain, which accounted to 2.7% of all time spent in this context. Even though transport, which accounted for 6.2 min, it is the context with the highest MVPA share observed in the sample (17.1%). Home MVPA represented 2.0% of time spent in the home domain and school MVPA made up 2.1% of total school time.

Sedentary behavior was observed in all four domains, with 188.6 min when in the leisure domain and 167.5 min at home, both representing over 60% of the time spent in each domain (61.8% and 67.7%, respectively). Even with fewer minutes spent in SB at school (63.5), this domain shows larger proportion of total time spent in SB

when compared to other domains (68.5%). Transport SB (7.5 min) accounted for 20.7% of time spent in such domain.

For weekend days, the leisure domain was also the one with the most MVPA minutes (10.0), representing 3.4% of time spent in the domain. Transport was the highest proportion (16.4%) and home, the lowest (2.5%). There was an increase in SB while in the home domain during the weekend (181.6 min), as well as leisure (195.1 min) and transport (13.1 min).

4. Discussion

This paper presented the procedures, protocol and results for data collection of objective environment, physical activity and sedentary behavior measures in a sample of Brazilian adolescents. The combination of methods made it possible to assess context-specific behavior as well as characteristics of participants and time spent in different domains. Participants in this study spent, on average week days, 21.7 min per day in MVPA, while most of the time (427.1 min) was spent in sedentary behavior. During weekend days, MVPA was achieved for 23.2 min while time spent in SB was 389.8 min.

There are few other studies that have evaluated context-specific behavior in adolescents (Collins et al., 2012; Dessing et al., 2013; Klinker et al., 2014a, 2014b; Quigg et al., 2010) and none in a Brazilian sample, therefore, direct comparisons with other studies are difficult. However, some results are comparable and other studies show adolescents spent most of the time in the school domain (Klinker et al., 2015; Maddison et al., 2010), contrary to what was found in this study. The regular Brazilian school system requires around five school hours per day, which will limit time spent in the school domain to a maximum of 300 min. Also, school time was defined only using a spatial definition that considered a GPS point to be 'in school' if the point was located on the school parcel, or up to 10 m from the school parcel, during reported self-reported school hours. Recent studies have used class time tables (Klinker et al., 2015) in combination with a spatial definition to increase the accuracy of time spent in school domain (Dessing et al., 2013).

Time spent in MVPA was higher while in the leisure domain, contrary to a study conducted in Europe (Klinker et al., 2014a, 2014b). However, the results were similar in proportion, where active transport accounted for over 17% of total time in the transport domain. Other

Table 2

Protocol compliance (n = 80) (Curitiba, Brazil, 2013).

	All participants	Participants wearing GPS	Participants with valid GPS data
Daily accelerometer and GPS wear time, median hours (IQR)	N/A	830.7 (714.6–939.8)	733.3 (538.3–835.4)
Number of valid week days, mean (range)	N/A	2.0 (0.0–7.0)	3.7 (2.0–5.0)
Number of valid weekend days, mean (range)	N/A	0.7 (0.0–3.0)	1.3 (0.0–2.0)

N/A = not applicable.

Table 3
Total, MVPA and sedentary times, in minutes, spent in different domains (Curitiba, Brazil, 2013).

DOMAIN	Total	WEEK n = 79		Total	WEEKEND n = 77	
		MVPA	SB		MVPA	SB
Home						
Median (IQR) %	247.4 (135.1–332.7)	5.0 (2.3–8.2)	167.5 (79.8–238.0)	261.1 (83.5–431.5)	6.6 (1.0–10.0)	181.6 (48.3–286.2)
100		2.0	67.7	100	2.5	69.5
School						
Median (IQR) %	92.6 (40.9–192.8)	2.0 (0.6–4.9)	63.5 (19.5–132.3)	–	–	–
100		2.1	68.5			
Transport						
Median (IQR) %	36.2 (18.6–66.8)	6.2 (2.5–13.0)	7.5 (2.0–20.7)	40.2 (4.8–52.6)	6.6 (0.0–7.3)	13.1 (0.2–16.7)
100		17.1	20.7	100	16.4	32.5
Leisure						
Median (IQR) %	305.0 (178.2–455.2)	8.5 (4.1–17.2)	188.6 (114.2–317.0)	288.8 (137.0–419.0)	10.0 (1.7–13.3)	195.1 (91.5–274.6)
100		2.7	61.8	100	3.4	67.5

MVPA: Moderate-to-vigorous physical activity; SB: Sedentary behavior; IQR: Interquartile range

studies have found active transport to contain a larger proportion of MVPA (Rainham et al., 2012) contributing to overall PA levels (Van Dyck et al., 2010).

Criteria for data validation are not yet well established for combined accelerometer and GPS points, however, most studies in high-income countries have used a minimum of one valid day ($> = 4$ h) (Carlson et al., 2016; Klinker et al., 2015; Quigg et al., 2010). A mean of five valid days, including week and weekend days, was fewer than in a study conducted in the United States where an average of seven days was considered valid (Dunton et al., 2013), but more than in a Danish study (average of 2.6 days) (Klinker et al., 2014a, 2014b).

This study is especially important in Latin America, where there has been a high concern for childhood obesity and non-communicable chronic diseases, beyond the increased levels of crime and violence, poor access to public transportation, leisure facilities and supportive environment for active transport and physical activity. Moreover, the region has experienced a lack of capacity to conduct the research needed to address physical inactivity (Sallis et al., 2016). As a consequence, during the recruitment phase, a few adolescents refused to wear the devices because they were afraid of being robbed. Participants' also claimed not wearing the devices for seven days because they did not want to be monitored (while skipping school or engaging in deviant behavior).

Using diary logs to understand data is helpful, but can be deceiving as well. There were cases where adolescents reported going to school but data showed otherwise. Fortunately, only one case of missing devices was reported throughout the entire study, which was later retrieved from the participants' home. Allowing participants to see and touch the devices, acknowledging they have no commercial value and are only used for research, and assuring they will not be instantly monitored could be beneficial for participation and compliance.

Although sample size is a limitation in this study, total participants' demographics did not differ from those providing GPS data, as expected from a sub-sample, and was similar to a North American study (Carlson et al., 2016). Nonetheless, with the same dataset it would be possible to answer other research questions satisfyingly as the unit of analysis could be changed depending on the outcome of interest. For example, when studying GPS-routes, a study with 37 participants generated 370 journeys (Badland et al., 2010). For this dataset, with an average of 12 routes per person, the sample size could be increased to 960.

Even though data collection procedures, data processing and analyses are not yet consistent, combining accelerometer and GPS data has been considered a promising methodology in studies evaluating the built environment, PA and SB (Krenn et al., 2011). In addition, future studies might consider collecting data on parents following similar

protocols and methodologies as parent's PA is a determinant for adolescent's PA (Ferreira et al., 2007).

5. Conclusions

The combination of GIS, GPS and accelerometry methods enabled assessment of PA and SB in different domains. Even though data collection procedures, data processing and analyses are not yet consistent, combining accelerometer and GPS data is a promising methodology in studies evaluating the built environment, PA and SB. This methodology has also showed to be feasible when conducting physical activity and built environment studies in an upper middle-income country context, where safety, crime and health issues can be important limitations. In this particular study we found adolescents spent most of their time in the home and leisure domains (> 500 min per day), spending over 60% of this time in sedentary behavior while only about 3% engaging in MVPA. Unveiling where and how adolescents engage on PA and SB can help design interventions to promote active lifestyles for this population.

Competing interests

The authors declare they have no competing interests.

Authors' contributions

COA was part of the coordinating team of Projeto E.S.P.A.Ç.O.S. Adolescentes. COA contributed to acquisition of data, project logistics, data cleaning and analyses and drafted the manuscript. JS was responsible for processing GPS, GIS and accelerometer data and design of the database. RR helped to conceive the study and participated in its design. All authors revised the manuscript critically, read and approved its final version.

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Transparency document

The Transparency document related to this article can be found, in the online version.

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