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When cities move children: Development of a new methodology to assess context-specific physical activity behaviour among children and adolescents using accelerometers and GPS

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ABSTRACT

This study presents a novel method to assess context-specific physical activity patterns using accelerometer and GPS. The method efficiency is investigated by providing descriptive results on the use of domains and subdomains, and assessing how much of children's and adolescents' daily activity time can be classified by these domains and subdomains. Four domains and 11 subdomains were defined as important contexts for child and adolescent behaviour. During weekdays ($n=367$) and weekend days ($n=178$) the majority of children and adolescents spent time in active transport, urban green space, clubs and sports facilities. Satisfactory method efficiency was found during weekdays. Natural experiments combined with objective assessment of context-specific behaviours hold the potential to create evidence on the effects of changes to the built environment on behaviour.

1. Introduction

Physical activity (PA) is recognised internationally as an important component of a healthy lifestyle—contributing to better physical, mental and social well-being (Andersen et al., 2011; Biddle and Asare, 2011; Floriani and Kennedy, 2008; Landry and Driscoll, 2012). However, 80% of adolescents worldwide do not comply with international public health guidelines on PA – 60 min daily – and the number of children who do not have an acceptable level of physical fitness is increasing (Pedersen and Andersen, 2011). Acceptable level of physical fitness was defined as maximal oxygen uptake lower than 34 ml of oxygen per kilogram of body mass per minute for girls and 38 ml of oxygen per kilogram of body mass per minute for boys. The built environment can influence children and adolescents' PA (Bauman et al., 2012). Improvements of the built environment, e.g. providing new activity space or improving the safety and attractiveness of existing facilities, may have the potential to promote PA and change movement patterns and have been identified as important components in obesity prevention among these groups by national and international health promotion advocates, experts and research groups. To date, studies on the built environment and PA have been characterized by inconsistent associations (Davison and Lawson, 2006; de et al., 2011; Ding et al., 2011).

Inconsistencies in correlation or longitudinal studies may be due to measuring only overall daily PA or PA in only one domain or subdomain instead of measuring the *context-specific PA patterns*. Context-specific PA patterns can be defined as daily PA assessed in total *and* in different domains and subdomains throughout the day, with *context* referring to the domain or subdomain in which behaviour occurs. Without context-specific objective measures, it is unclear how and where PA behaviour takes place. How does PA in one domain or subdomain relate to PA behaviour in other domains/subdomains? (Gomersall et al., 2013; Rowland, 1998). What are the relations between domains such as school, leisure, home or transport? (Fremeaux et al., 2011). Further, can PA be specified into one or more subdomains (e.g. urban green space, sports facilities, recess)? There is some documentation that an association between the built environment and PA is context-specific (Ferreira et al., 2007; Sallis et al., 2000). No widely accepted methodology to objectively assess context-specific behaviour patterns has been developed to date.

Another limitation in research into the built environment and behaviour has been the use of self-reported measurements, or parent-reported measures in the case of younger children. Self-reported measurement of exposure to intervention or self-reported

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assessment of context-specific behaviours, such as PA, introduces the potential for systematic biases, such as recall and social desirability bias (Evenson et al., 2008), or an underestimation of certain daily life activities (Sherar et al., 2011), such as picking up groceries or taking the garbage out. Global Positioning System (GPS) units assessing locations and accelerometer measurements assessing PA can be combined to improve upon self-reports.

In 2009, an opportunity arose to conduct a natural experiment in Copenhagen, Denmark. Planned major urban renewal made it possible to design a study with the aim to evaluate the effect of changes to the built environment on local children and adolescents' movement patterns using combined GPS and accelerometer data by assessing the context-specific time and PA patterns. Children aged 11–16 years old were chosen as the target group for this study as the level of PA often declines from childhood to adolescence (Riddoch et al., 2004). In addition, the content of urban renewal projects combined with changes in the local neighbourhood is hypothesised to be particularly important for PA in this age group due to limited roaming distances (Jones et al., 2009).

This paper aims to present a methodology that enables the assessment of objective context-specific patterns by the use of GPS and accelerometers as this methodology has the potential to assess the effects of changes to the built environment on physical activity behaviour. The methodology is based on socio-ecological health behaviour models and in particular Sallis' et al. (2006) ecological model of PA with four active living domains and determinants related to active living. For children and adolescents this theoretical approach corresponds to the following active living domains: leisure, school, transport and home. These domains are rather broad, and it is necessary to further include a range of subdomains, in order to be able to more precisely assess context-specific behaviour patterns. Subdomains can be locations, facilities or organizational constructs within domains. Recess and Physical Education (PE) are examples of organizational opportunities found to be related to PA during school hours (Guinhouya et al., 2009). Locations such as playgrounds (Quigg et al., 2010; Reed and Hooker, 2012) and urban green space (Lachowycz et al., 2012; Wheeler et al., 2010) or facilities such as sports facilities (Niclasen et al., 2012), school grounds (Dencker et al., 2012), clubs (after school programs in Denmark) (Beets et al., 2009), and shopping centres (Oreskovic et al., 2012) are all potential subdomains for PA during leisure time as they seem to be positively correlated with PA. Within the transport domain active and passive transport are two distinct PA behaviours (Heath et al., 2012). As such the methodology presented in this paper proposes that to fully understand context-specific patterns, behaviour has to be assessed within these domains and subdomains.

The specific aims of this paper are to first describe a novel method to assess context-specific physical activity patterns developed and used on the WCMC study and second to investigate the method efficiency by providing descriptive results on the use of domains and subdomains, and assessing how much of the total time can be assigned to these predefined contexts using the new methodology. Only baseline results from the WCMC study pertaining to the use of and time spent in domains and subdomains are presented in this paper. The context-specific moderate to vigorous PA (MVPA) patterns, outdoor time and outdoor MVPA patterns have been reported elsewhere as have parts of the methodology (Klinker et al., 2014a, 2014b).

2. Material and methods

2.1. Setting

In 2009, the local government of Copenhagen planned a range of major changes to the built environment in and around the Haraldsgade district in Copenhagen, the capital of Denmark. The WCMC study was conceived to evaluate the effects of these changes on the local children and adolescents' context-specific behaviour patterns. The Haraldsgade district was built in 1860–1920 and was previously one of Copenhagen's first large industrial areas. Commercial and industrial land uses as well as large public housing estates now characterized the neighbourhood. Public open spaces were scarce. There were few sports facilities and almost no public green spaces. Approximately 9300 people resided in the Haraldsgade district, 45% lived in public housing estates compared with 19% in the Copenhagen municipality, and one out of three were immigrant or descendant of immigrants compared with 19% in Copenhagen municipality and 10% in Denmark (Copenhagen Municipality, 2007; Danmarks Statistik, 2013). Approximately 1800 children lived in the area of which 200 were immigrants and 1100 descendants of immigrants (Copenhagen Municipality, 2007).

2.2. Participant recruitment

Eligible participants were children and adolescents in grade 5–8 attending four public schools located in or just outside the Haraldsgade district. The details of the participant recruitment have been reported elsewhere (Klinker et al., 2014a). The Danish Ethical Regional Committee reviewed the study protocol and concluded that formal ethics approval was not required. The study is registered and approved by the Danish Data Protection Agency (reference number: 2009-41-3943).

2.3. Data collection

Baseline data were obtained in April–June 2010 (three schools) and September 2011 (one school). On day 1 of baseline data collection, researchers fitted the participants with the equipment and they were provided with verbal and written instructions on belt wear and removal, a GPS charger, and information on how to charge the GPS every night. The participants also received a short standardized daily diary. Finally, the students' or the students parents' mobile phone numbers were recorded in order for them to receive text message reminders thus improving compliance and data quality. After seven days of data collection, the equipment was collected. During the data collection period, the students completed an internet-based questionnaire during school hours. To stimulate a high participation and return of the equipment, classes were offered a minor incentive for compliance.

2.4. Measurements

2.4.1. Physical activity and locations

Objective PA was assessed using the tri-axial Actigraph GT3X Activity Monitor during seven consecutive days. The accelerometer uses a piezoelectric acceleration sensor to convert signals to counts and sum them over a user-specified time sampling interval, called an epoch. Activity counts are recorded to the internal memory of the accelerometer and can later be downloaded and processed on a computer (Chen and Basset, 2005). The accelerometer has the ability to yield measures of amount, frequency, intensity and duration of children's physical activity (Sherar et al., 2011). The data were recorded at 2 s epochs and only data from the vertical axis were used in this study. Data from the returned monitors were downloaded using the ActiLife 4.4.1 software and screened for file size to detect potential equipment or download problems. QStarz BT-Q1000X GPS units were used to record the locations of the participants. The GPS units were set-up using the open source BT747 software (www.bt747.org). Units were configured to record date, time, longitude, latitude, height, speed, distance, and the number of satellites in view and used every 15 s. The units were set to stop logging when the memory was full. After data collection, the data were downloaded using bt747 software and screened for file size to detect potential equipment or download problems. All students were instructed to wear both monitors on a belt on their hip, opposite sites, during waking hours and to take it off only for showering, bathing, or doing water sports. They were instructed to not turn the GPS off during data collection.

2.4.2. Socio demographic and employment characteristics

Information on student immigrant status and parental employment status were obtained from Statistics Denmark using a unique personal registration number assigned to all in Denmark (Pedersen, 2011). Parental employment status was dichotomized as both parents working versus one or both parents being unemployed. Participants were dichotomized as Danish versus immigrant (not born in Denmark) or descendent of immigrants (born in Denmark but parents not born in Denmark).

2.4.3. Diary and class timetables

During data collection, students were asked to fill out a short diary every evening. The diary contained questions about school (non-)attendance and if it had been a regular school day (if not, why?). Participants were also asked about their non-wear of the equipment. The schools provided detailed class timetables for the specific data collection period including information on start and end of school days, recess and physical education (PE).

2.4.4. Questionnaire

All students were instructed to fill out a questionnaire individually on a computer during school. The questionnaire contained questions on health related behaviour, self-reported health status including weight and height, perceived neighbourhood characteristics (physical environment, safety, etc.) and possibilities for being physically active in the neighbourhood and school setting. BMI was later calculated using self-reported height and weight using Cole et al. (2000) and included as a continuous variable. Grade was dichotomized into grade 5 and 6 (approximately 11–13 years) versus grade 7 and 8 (approximately 13–16 years) to approximate “children” and “adolescents”.

2.5. Data processing

2.5.1. The personal activity and location measurement system (PALMS)

The personal activity and location measurement system (PALMS) (Anon, 2013), developed by the Centre for Wireless and Population Health Systems, University of California, San Diego, is a web-based application system capable of processing and combining activity data (accelerometers) and location data (GPS). All accelerometer files were aggregated to 15-s epochs (or data/time points) using PALMS to match the GPS data points using Evenson cutpoints, which have been recommended to estimate PA intensities among children (Evenson et al., 2008; Trost et al., 2011). Continuous periods of 60 min of zero values were classified as accelerometer non-wear time, and were removed from the data (Adams et al., 2013; Colley et al., 2011; Sherar et al., 2011).

All GPS files were processed using PALMS with user defined settings. PALMS identified invalid data points using extreme speed (>130 km/h) or extreme changes in distance (>1000 m) and elevation (>100 m) between two data points, and replaced invalid points by imputing data from the last known valid point, for up to 10 min. Using algorithms that utilize the signal-to-noise-ratio (SNR) PALMS categorized data points as occurring indoors or outdoors. PALMS marked locations as outdoor when the total SNR of all satellites in view exceeded a threshold of 250 (Tandon et al., 2013). Furthermore, PALMS identified and categorized trips (defined as a continuous period of movement of at least 3 min, allowing for stationary periods of maximum 5 min) into three modes: walking ($>=1$ km/h, <10 km/h), biking ($>=10$ km/h, <25 km/h) and in a vehicle ($>=25$ km/h)(Kerr et al., 2012a).

Processed GPS data were then matched to the accelerometer data based on the timestamps of each GPS point, forming a PALMS dataset of combined accelerometer and GPS data. If no GPS signal was available, the accelerometer epochs were retained to calculate a full daily time pattern and daily PA variables. The PALMS dataset consisted of all collected data in 15 s epochs containing information on: date, time, location (GPS coordinates: latitude and longitude), PA intensity, outdoor activity (is epoch taking place outdoor: yes, no), and trip mode (epoch part of a trip: yes, no; if yes: walk, bicycle, or vehicle epoch). As no available data management systems were able to handle the data load for even more simple procedures, and in particular not specific requirements wanted in this study, a purpose-built PostgreSQL database was developed with the aim of developing context-specific measures by means of allocating data to domains and subdomains.

2.5.2. Aggregation of data into domains and subdomains

A PostgreSQL database capable of combining the PALMS dataset with information from participant diaries, class timetables and location data from a Geographical Information Systems (GIS, ArcGIS 10.1) was developed to compute variables for domains and subdomains to allow for a context-specific behaviour assessment. Fig. 1 displays the dataflow and methodology applied. The database was set up to assign each epoch into domains and/or subdomains based on a decision tree. After all epochs had been assigned the database aggregated all epochs into individual daily measures. Below is a description of the decision rules applied:

1. All epochs occurring during scheduled school hours during weekdays were assigned to and aggregated as the school domain based on class timetables and individual deviations to these tables based on the daily diaries. Based on the same method, the subdomains recess (an aggregate of all scheduled recesses during a school day) and PE were identified within the school domain.
2. All epochs during all days falling within the participant home were then assigned to and aggregated as the home domain. All students' primary addresses were geocoded and each home was manually digitalized in GIS. A house was defined in GIS as the parcel (the house and garden), while an apartment was defined as the building and adjacent outdoor area. This adjacent outdoor area was also manually digitalized in GIS.
3. The Municipality of Copenhagen provided addresses of public schools, clubs, sports facilities and playgrounds, enabling a manual digitization of school grounds, clubs, sports facilities and playgrounds in GIS. All urban green spaces were available as a GIS layer from the Danish Geodata Agency. Major indoor shopping centers were identified online, and manually digitalized in GIS. The database afterwards assigned epochs falling within these places or facilities to form leisure subdomains.
4. All epochs classified by PALMS as part of a trip were next assigned and aggregated into the transport domain. These trips were later dichotomized into the subdomains active (walking, biking) and passive (vehicle) transport.
5. The epochs still not assigned to these predefined domains or subdomains through steps 1–4 were assigned and aggregated into the subdomain *other places*. This subdomain was made up of two kinds of epochs: (a) combined accelerometer and GPS epochs not assigned during any of the above described steps or

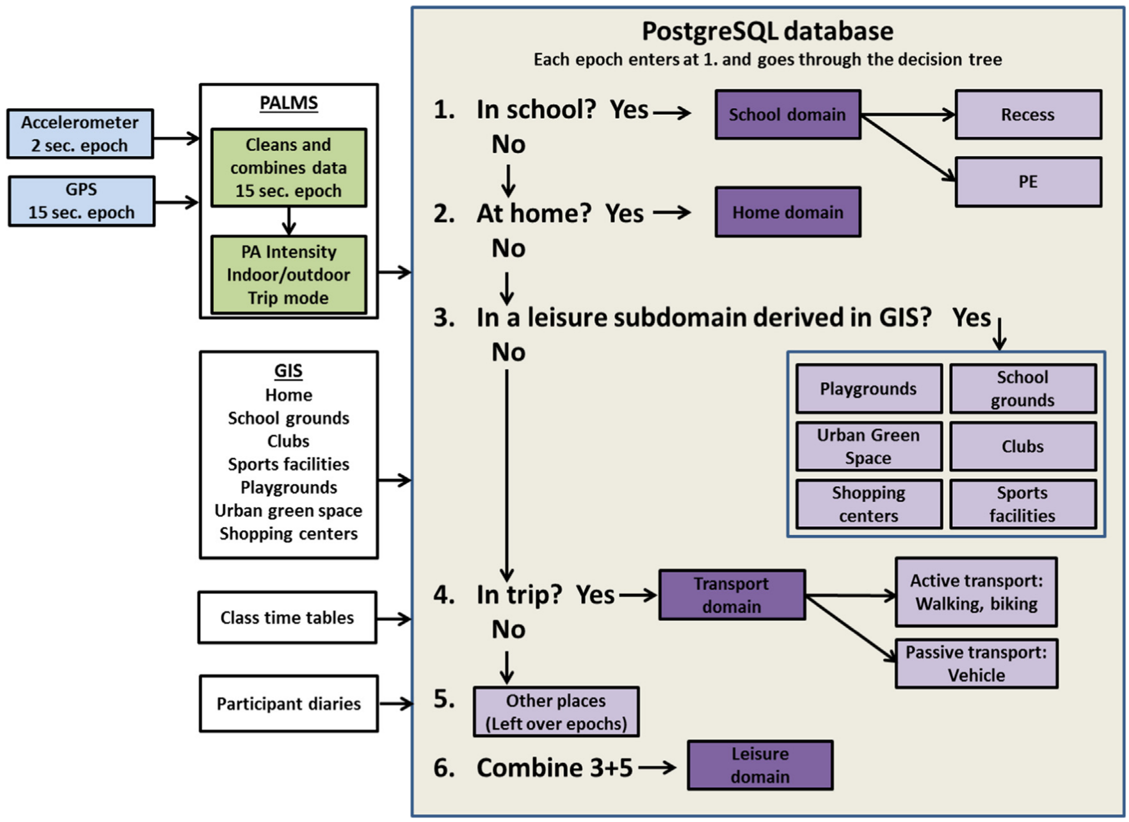

Fig. 1. Dataflow and methodology. PALMS combines accelerometer and GPS data and adds PALMS derived variables. The PALMS dataset enter the database along with information from a GIS, class time tables and participant diaries. The database goes through a decision tree to assign each epoch to domains and/or subdomains.

(b) accelerometer epochs without location (GPS) data. These latter epochs can for instance occur if the GPS loses signal inside a building or if the GPS runs out of battery.

6. The subdomains school grounds, clubs, sports facilities, playgrounds, urban green space, shopping centers and *other places* were later aggregated to constitute the leisure domain.

The study area manually digitized in GIS was defined as all GPS epochs falling within a 10 by 10 km^2 square with its center in the Haraldsgade district. Very few GPS points were falling outside this area and these GPS points did not seem to be part of habitual behavior. A 10 m Euclidian buffer was applied to all GIS derived measures to account for GPS signal and location errors, which should capture almost 80% of GPS points correctly (Schipperijn et al., 2014). In this way all epochs for all participants were assigned to four domains and 11 subdomains as contexts in which time and activities occurred. The database was then used to aggregate total and context-specific daily variables on the number of users (n), time spent (minutes) and PA intensities (minutes) for all participants. This aggregated dataset now had a manageable size and was imported into a statistical software package for further analyses. The outcome measures used in this study are the number (and %) of participants who were present in domains or subdomains during data collection and the median daily time spent across all valid participants in domains and subdomains by week- and weekend days, in total and by age and gender.

2.6. Analyses

Stata 12 SE was used to identify valid participants defined by having at least one valid week- or weekend day of at least 9 h accelerometer and GPS wear time. All valid participants with one or more days of zero time spent at home were further investigated to determine if they resided in a secondary home during data collection. If these participants had indicated in the questionnaire that their parents did not live together, and that they during data collection resided in the secondary parents' home, participant data were removed. This was done as it was not possible to geocode the secondary parents' address. As the participants were fitted with the equipment during different times on day 1 of data collection, day 1 was removed to allow for a full day pattern analyses. All valid days were retained and aggregated to individual daily week- and weekend means. Weekdays and weekends were analysed separately to retain most participants and as the domains are not comparable e.g. students do not attend school during weekend days. Descriptive statistics were calculated using frequency distributions (number (n) and proportion (%)), mean and standard deviation (SD), or median and interquartile ranges (IQR) for non-normally distributed variables. Univariate analyses were performed using χ^2-test, t-test or Wilcoxon rank-sum to test differences in baseline characteristics between children with complete and incomplete data. Protocol compliance among valid participants was expressed as wear times for accelerometer and GPS', number of valid week- and weekend days and number of returned diaries. Method efficiency was assessed by looking at daily accelerometer wear time without GPS data and daily GPS time not assigned to predefined domains and subdomains.

3. Results

3.1. Participants, protocol compliance and methods efficiency

A total of 623 children were invited to participate in the WCMC study at baseline. Of these, 45 parents and 55 students refused to participate, leaving a total sample of 523 participants (83.9%). A total of 367 (70.2%) of the participants had at least one valid weekday of 9 h accelerometer and GPS data, and 178 (34.0%) had at least one valid weekend day of 9 h combined data. Fig. 2 displays the baseline participants for the WCMC study. There were no differences in age, gender, BMI, parental employment status and immigrant status between participants who fulfilled the inclusion criteria during weekdays ($n=367$) and those who were excluded (all $p>0.1$). During weekends no differences were found for those included ($n=178$) compared to those who were excluded by gender, BMI and employment status but a greater dropout was observed for Danish participants ($p=0.023$) and for adolescents ($p=0.042$). Across week- and weekend days differences in the drop-out across schools was observed ($p<=0.001$).

During weekdays ($n=367$) the median hours of accelerometer wear time was 14.1 (IQR 13.2–14.8) and mean valid days were 2.5 (range 1–4) (Table 1). During weekend days ($n=178$) the median hours of accelerometer wear time was 12.5 (IQR 11.5–13.6) and mean valid days were 1.4 (range 1–3). To assess method efficiency it was investigated how much time was *not* assigned using the developed methodology. During weekdays 11.5% of the GPS points were not assigned to the predefined domains and subdomains (Table 1). During weekend days 26.9% of the GPS epochs were not assigned. A small percent of the participant accelerometer data did not contain GPS epochs and was also not assigned using the methodology—7.7% during weekdays and 6.9% during weekend days.

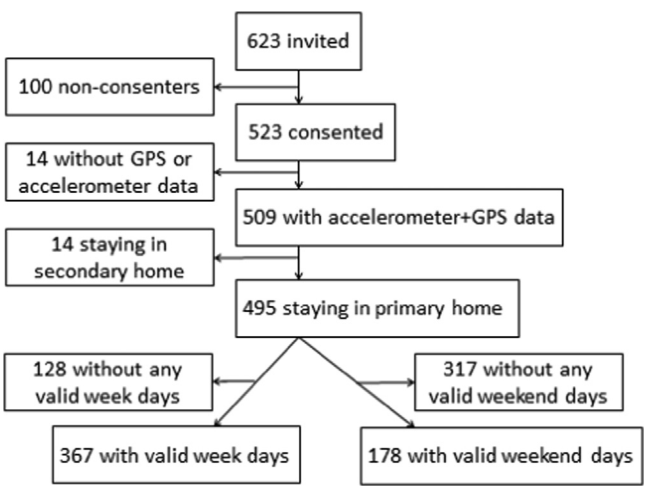

Fig. 2. Study participants and drop-out at baseline.

3.2. Presence at domains and subdomains

Table 2 provides results on the number of students who were present in domains and subdomains during data collection, by weekdays and weekend days, gender and age. During *weekdays* ($n=367$), all participants were present in school and recess and almost all participants were at school grounds outside scheduled school hours (98.0%), in active transport (99.1%) or in urban green space (95.9%). A less proportion of participants were at clubs (65.1%), in passive transport (67.0%) or at sports facilities (68.4%). A bit less than half of the participants were at playgrounds during weekdays (46.0%). A bit more than one quarter (27.2%) were in a shopping center during weekdays.

During *weekends* ($n=178$), almost all participants were in active transport (93.3%) (Table 2). A high proportion of participants were also in urban green space (86.0%). A total of 75.3% of the participants were in passive transport during weekends while less than half were at clubs (42.1%) or sports facilities (42.7%). A bit more than one third (35.4%) of the participants were at school grounds, 27% were at playgrounds and 24.2% were at shopping centers during weekends.

A higher proportion of boys compared to girls were in clubs and sports facilities during week and weekend days while a higher proportion of girls compared to boys were in urban green space and engaged in passive transport during weekends. A higher proportion of adolescents compared to children were at shopping centers and engaged in passive transport during weekend- and weekend days. A higher proportion of adolescents compared to children were at sports facilities during week days while the opposite was true for weekends. A higher proportion of children were at playgrounds during weekdays with no differences observed between children and adolescents during weekend days.

Table 1
Protocol compliance, method efficiency and demographic characteristics for valid participants, by week and weekend days.

	Week days	*n*	Weekend days	*n*
Protocol compliance				
Daily accelerometer wear time, median hours (IQR)	14.1 (13.2–14.8)	367	12.5 (11.5–13.6)	178
Daily GPS time, median hours (IQR)	12.7 (11.6–13.5)	367	11.3 (10.1–12.4)	178
No of valid week days, mean (range)	2.5 (1–4)	367	2.7 (0–4)	178
No of valid weekend days, mean (range)	0.9 (0–3)	367	1.4 (1–3)	178
Diaries, *n* (%)	307 (83.7)	367	148 (83.2)	178
Method efficiency				
Daily accelerometer wear time without GPS data, median minutes (%)	62.8 (7.7)	367	51.0 (6.9)	178
Daily GPS time not assigned to predefined domains and subdomains, median minutes (%)	92.4 (11.5)	367	195.7 (26.9)	178
Demographic characteristics				
Gender, girls, *n* (%)	192 (52.3)	367	96 (53.9)	178
Age, children (grade 5–6), – (%)	219 (59.7)	367	113 (63.5)	178
BMI, mean (SD)[a]	18.8 (3.2)	346	18.6 (3.0)	172
Immigrant status[b]		360		176
Danish, *n* %	134 (37.2)		53 (30.1)	
Immigrant or descendent, *n* (%)	226 (62.8)		123 (69.9)	
Parental employment status[c]		355		175
Both parents working, *n* (%)	198 (55.8)		90 (51.4)	
One or both parents unemployed, *n* (%)	157 (44.2)		85 (48.6)	

BMI, body mass index; IQR, inter quartile range; SD, standard deviation.

[a] Missing $n=6$–21.
[b] Missing $n=2$–7.
[c] Missing $n=3$–12.

3.3. Daily time in domains and subdomains

Tables 3 and 4 provide results on the median time accumulated by all valid participants in domains and subdomains during data collection, by weekdays and weekend days, gender and age. Table 3 shows the context-specific time pattern during *weekdays* ($n=367$). The majority of the participants' time during weekdays was spent in the school domain (302.3 min), followed by leisure (247.1 min), home (206.6 min) and the transport domain (47.2 min). Among the seven investigated leisure subdomains, the majority of time was spent in other places (166.8 min), followed by school grounds (20.6 min) and urban green space (7.4 min). Time spent in other places may for instance be time spend visiting friends or family. For clubs, sports facilities playgrounds and shopping centers the median daily time spent in these places was less than 1 min, however, with some participants accumulating much time in these places, e.g. the upper range for clubs was 243.9 min, for sports facilities it was 166.3 and for playgrounds it was 352.8 min.

The majority of the participants' time during *weekend* days ($n=178$) was spent in the leisure domain (337.3 min), followed by home (308.6 min) and the transport domain (63.8 min) (Table 4). The vast majority of time in the leisure domain was spent in other places (279.4 min) with urban green space (4.1 min) being the only other subdomain with a median value above 0 min. Again, the upper range for these subdomains indicates that some participants accumulated quite a lot of time in these places, e.g., some participants accumulated a daily median of 210.8 min at school grounds, 292.3 at sports facilities while the maximum time spent daily in playgrounds was 135.9 min.

Boys compared to girls spent more time in leisure while girls spent more time at home. Children compared to adolescents spent more time in leisure while adolescents spent more time in active transport. A similar gender and age pattern was found across week and weekend days.

4. Discussion

This paper presented the methodology to assess context-specific behaviours, which was developed by the study team for the WCMC study, a natural-experiment-based study aimed at assessing the impacts of changes in built environment on children's and adolescents'

Table 2
Percentage and number of students who were present at any time during data collection in domains and subdomains, by weekdays and weekend days, in total, and by gender and age.

	Week days										**Weekend days**									
	Total		**Girls**		**Boys**		**Children**		**Adolescent**		**Total**		**Girls**		**Boys**		**Children**		**Adolescent**	
	%	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***N***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***
Total	**100.0**	**367**	100.0	192	100.0	175	100.0	219	100.0	148	**100.0**	**178**	100.0	96	100.0	82	100.0	113	100.0	65
Leisure	**100.0**	**367**	100.0	192	100.0	175	100.0	219	100.0	148	**100.0**	**178**	100.0	96	100.0	82	100.0	113	100.0	65
School grounds	**98.6**	**362**	98.4	189	98.9	173	99.1	217	98.0	145	**35.4**	**63**	35.4	34	35.4	29	35.4	40	35.4	23
Clubs	**65.1**	**239**	61.5	118	69.1	121	64.4	141	66.2	98	**42.1**	**75**	46.9	45	36.6	30	42.5	48	41.5	27
Sports facilities	**68.4**	**251**	63.5	122	73.7	129	66.2	145	71.6	106	**42.7**	**76**	44.8	43	40.2	33	46.0	52	36.9	24
Playgrounds	**46.0**	**169**	45.8	88	46.3	81	50.2	110	39.9	59	**27.0**	**48**	28.1	27	25.6	21	26.5	30	27.7	18
Urban Green Space	**95.9**	**352**	95.3	183	96.6	169	95.4	209	96.6	143	**86.0**	**153**	90.6	87	80.5	66	86.7	98	84.6	55
Shopping center	**27.2**	**100**	28.6	55	25.7	45	23.7	52	32.4	48	**24.2**	**43**	25.0	24	23.2	19	21.2	24	29.2	19
Other places	**100.0**	**367**	100.0	192	100.0	175	100.0	219	100.0	148	**100.0**	**178**	100.0	96	100.0	82	100.0	113	100.0	65
School	**100.0**	**365**	100.0	191	100.0	174	100.0	218	100.0	147										
Recess	**100.0**	**360**	100.0	189	100.0	171	100.0	213	100.0	147										
PE	**100.0**	**206**	100.0	112	100.0	94	100.0	106	100.0	100										
Transport	**99.7**	**366**	99.5	191	100.0	175	100.0	219	99.3	147	**96.6**	**172**	95.8	92	97.6	80	95.6	108	98.5	64
Active	**99.2**	**364**	98.4	189	100.0	175	99.1	217	99.3	147	**93.3**	**166**	91.7	88	95.1	78	90.3	102	98.5	64
Passive	**67.0**	**246**	67.7	130	66.3	116	63.9	140	71.6	106	**75.3**	**134**	80.2	77	69.5	57	71.7	81	81.5	53
Home	**99.7**	**366**	99.5	191	100.0	175	99.5	218	100.0	148	**97.8**	**174**	97.9	94	97.6	80	97.3	110	98.5	64

Table 3
Daily median time in minutes and range during weekdays, for total wear time, and by domains and subdomains, stratified by gender and age.

	Weekdays									
	Total Median (Range)	***n***	**Girls Median (Range)**	***n***	**Boys Median (Range)**	***n***	**Children Median (Range)**	***n***	**Adolescent Median (Range)**	***n***
Total wear time	**845.3 (578.5–1240.5)**	**367**	851.8 (586.0–1060.6)	192	822.9 (578.5–1240.5)	175	837.1 (601.5–1240.5)	219	850.7 (578.5–1051.0)	148
Leisure	**247.1 (27.0–653.5)**	**367**	237.3 (27.0–653.5)	192	265.4 (49.5–641.4)	175	265.1 (42.5–653.5)	219	227.3 (27.0–505.3)	148
School grounds	**20.6 (0.0–245.5)**	**367**	20.9 (0.0–160.9)	192	19.1 (0.0–245.5)	175	22.8 (0.0–177.9)	219	17.0 (0.0–245.5)	148
Clubs	**0.3 (0.0–243.9)**	**367**	0.3 (0.0–173.4)	192	0.5 (0.0–243.9)	175	0.3 (0.0–210.3)	219	0.4 (0.0–243.9)	148
Sports facilities	**0.7 (0.0–166.3)**	**367**	0.5 (0.0–117.5)	192	1.2 (0.0–166.3)	175	0.6 (0.0–166.3)	219	0.8 (0.0–106.1)	148
Playgrounds	**0.0 (0.0–352.8)**	**367**	0.0 (0.0–201.5)	192	0.0 (0.0–352.8)	175	0.1 (0.0–352.8)	219	0.0 (0.0–201.5)	148
Urban Green Space	**7.4 (0.0–381.6)**	**367**	6.7 (0.0–381.6)	192	8.4 (0.0–111.1)	175	7.4 (0.0–381.6)	219	7.4 (0.0–219.3)	148
Shopping center	**0.0 (0.0–31.9)**	**367**	0.0 (0.0–31.9)	192	0.0 (0.0–22.6)	175	0.0 (0.0–31.9)	219	0.0 (0.0–21.3)	148
Other places	**166.8 (4.5–652.8)**	**367**	161.7 (4.5–652.8)	192	169.8 (21.0–530.1)	175	167.5 (4.5–652.8)	219	166.1 (17.0–487.8)	148
School	**302.3 (132.8–399.8)**	**365**	303.1 (194.8–399.8)	191	301.3 (132.8–399.8)	174	299.7 (132.8–399.8)	218	313.5 (164.0–399.8)	147
Recess	**54.5 (14.8–84.3)**	**360**	54.5 (14.8–84.3)	189	54.5 (14.8–84.3)	171	54.5 (14.8–84.3)	213	54.5 (34.6–84.3)	147
PE	**89.8 (5.3–99.8)**	**206**	89.8 (15.3–99.8)	112	89.8 (5.3–99.8)	94	89.8 (17.5–89.8)	106	89.8 (5.3–99.8)	100
Transport	**47.2 (0.0–172.8)**	**367**	51.7 (0.0–172.8)	192	43.9 (2.8–157.0)	175	41.5 (2.1–172.8)	219	62.0 (0.0–159.5)	148
Active	**33.3 (0.0–159.5)**	**367**	34.0 (0.0–159.5)	192	31.8 (2.8–124.7)	175	29.2 (0.0–156.0)	219	38.9 (0.0–159.5)	148
Passive	**5.6 (0.0–123.2)**	**367**	7.5 (0.0–79.6)	192	5.1 (0.0–123.2)	175	4.8 (0.0–123.2)	219	9.0 (0.0–79.6)	148
Home	**206.6 (0.0–605.9)**	**367**	224.6 (0.0–605.9)	192	196.6 (9.8–439.8)	175	203.1 (0.0–505.4)	219	214.2 (17.3–605.9)	148

Table 4
Daily median time in minutes and range during weekend days, for total wear time, and by domains and subdomains, stratified by gender and age.

	Weekend days									
	Total		Girls		Boys		Children		Adolescent	
	Median (Range)	*n*	Median (Range)	*n*	Median (Range)	*n*	Median (Range)	*n*	Median (Range)	*n*
Total wear time	**748.8 (559.5–1440.0)**	**178**	739.6 (575.3–1167.3)	96	768.0 (559.5–1440.0)	82	765.4 (571.0–1440.0)	113	738.0 (559.5–1144.5)	65
Leisure	**337.3 (16.3–1010.8)**	**178**	324.9 (16.3–1010.8)	96	344.1 (20.3–872.5)	82	344.8 (33.8–1010.8)	113	317.5 (16.3–872.5)	65
School grounds	**0.0 (0.0–210.8)**	**178**	0.0 (0.0–126.0)	96	0.0 (0.0–210.8)	82	0.0 (0.0–172.9)	113	0.0 (0.0–210.8)	65
Clubs	**0.0 (0.0–87.3)**	**178**	0.0 (0.0–87.3)	96	0.0 (0.0–75.9)	82	0.0 (0.0–87.3)	113	0.0 (0.0–42.8)	65
Sports facilities	**0.0 (0.0–292.3)**	**178**	0.0 (0.0–292.3)	96	0.0 (0.0–133.0)	82	0.0 (0.0–133.0)	113	0.0 (0.0–292.3)	65
Playgrounds	**0.0 (0.0–135.9)**	**178**	0.0 (0.0–54.0)	96	0.0 (0.0–135.9)	82	0.0 (0.0–135.9)	113	0.0 (0.0–72.8)	65
Urban Green Space	**4.1 (0.0–283.5)**	**178**	5.1 (0.0–283.5)	96	3.8 (0.0–243.8)	82	4.0 (0.0–244.3)	113	5.8 (0.0–283.5)	65
Shopping center	**0.0 (0.0–101.0)**	**178**	0.0 (0.0–62.3)	96	0.0 (0.0–101.0)	82	0.0 (0.0–101.0)	113	0.0 (0.0–25.6)	65
Other places	**279.4 (16.0–865.0)**	**178**	265.4 (16.0–865.0)	96	289.8 (20.3–822.3)	82	286.0 (28.3–865.0)	113	265.5 (16.0–822.3)	65
Transport	**63.8 (0.0–266.3)**	**178**	76.8 (0.0–248.5)	96	53.4 (0.0–266.3)	82	54.8 (0.0–248.5)	113	80.0 (0.0–266.3)	65
Active	**35.3 (0.0–238.3)**	**178**	37.6 (0.0–188.8)	96	34.1 (0.0–238.3)	82	30.5 (0.0–148.5)	113	45.5 (0.0–238.3)	65
Passive	**12.6 (0.0–242.0)**	**178**	13.2 (0.0–242.0)	96	11.8 (0.0–131.1)	82	11.3 (0.0–242.0)	113	15.0 (0.0–187.5)	65
Home	**308.6 (0.0–1057.8)**	**178**	323.4 (0.0–692.8)	96	294.1 (0.0–1057.8)	82	313.8 (0.0–1057.8)	113	308.3 (0.0–818.8)	65

PA behaviours. It also presented the assessment of the efficiency of the methodology in assigning epochs to four domains and 11 subdomains. Finally, some of the baseline participant characteristics have been presented.

The number of natural experiments that aim to evaluate changes to the built environment on PA behaviours among children is increasing but they are still scarce (Bohn-Goldbaum et al., 2013; Quigg et al., 2012; Smith et al., 2012). The innovation in the WCMC study is the possibility to objectively evaluate total daily context-specific behaviour as it is otherwise not possible to rule out substitution as expressed in the Activitystat hypothesis (Gomersall et al., 2013). The WCMC study includes objective measures of both PA and locations for local children and adolescents residing in an area undergoing major changes to the built environment. By using a method that allows for the assessment of context-specific behaviours, as demonstrated in this study, the WCMC study has the potential to assess the effects of changes to the built environment on behaviour (Ding et al., 2011; Ferreira et al., 2007; Sallis et al., 2000) but can also be used as a pre-intervention tool to help planners place facilities to reach an intended target group. More than 80% ($n=523$) of the 623 invited students agreed to participate in this study. The protocol compliance (wearing the equipment from getting up to going to bed) was reasonable for weekdays (74%, $n=367$) and moderate for weekend days (36%, $n=178$). However, with only small differences found between the included and excluded participant on important background characteristics. The included participants had a daily median of more than 11 h of accelerometer and GPS time and this allowed for full day pattern analyses.

This paper presented a method to objectively assess context-specific behaviour patterns. Based on theory and literature on domains and places for child and adolescent PA, we identified four domains and 11 subdomains as potential contexts. The database combines accelerometer and GPS data with GIS and other types of data (e.g. information from participant diaries and class time tables) to assess the context-specific behaviour patterns by week- and weekend days in the WCMC study population. We found good method efficiency during weekdays with only 11.5% of the GPS points not being assigned to the predefined domains and subdomains. During weekend days the methodology had modest efficiency, with 26.9% of the GPS epochs not assigned to the predefined contexts. A random selection of the GPS points not assigned revealed that these epochs predominantly consisted of time spent in houses or apartments (other than own home), or hanging out on the streets. It seems intuitively reasonable to assume that more time is spent visiting friends or family during weekends compared to weekdays and this may explain the larger amount of non-assigned GPS points during weekends. Dividing the subdomain *other places* (consisting of non-assigned GPS points and accelerometer epochs without location data) into *indoors – not at home* and *outdoor – in streets* may be a way to reduce the number of non-assigned epochs. A small percent of the participant accelerometer data did not have matching GPS data and was not assigned using the methodology; 7.7% during weekdays and 6.9% during weekend days. Participants were carrying both accelerometer and GPS on the same belt, and it is reasonable to assume that the difference between accelerometer and GPS data was likely caused by technical problems with the GPS outside of the participant's influence (e.g. faulty instruments or loss of signal), or due to participants forgetting to recharge the device overnight. The continuing development of GPS trackers leads to improvements both in terms of battery life and data storage capacity, possibly leading to an even smaller difference in future studies. The difference between accelerometer and GPS wear time would potentially be higher had we chosen only to use location data to assign epochs to the assessed domains and subdomains as done in a recent study by Dessing et al. (2013). Instead we chose to assign all epochs occurring during scheduled school hours to the school domain based on class timetables and student diaries. Only behavior occurring at school grounds outside scheduled school hours was assigned to the leisure subdomain school grounds. This allows for a distinction between behavior during scheduled school hours and leisure time behavior on school grounds which is important as different correlates potentially apply to behavior in these contexts, e.g. recess activities may be initiated by teachers while activities outside school hours are initiated by children or adolescents themselves. Also, in Denmark school grounds are open for public access outside school hours and are considered an important context for leisure time behavior. We found that during weekdays the median time spent at school grounds after scheduled school hours was 20.6 min (range 0–245.5) with 98.6% of participants using school grounds. In weekends the median time was zero minutes (range 0–210.8) with 35.4% of the participants using school grounds. These results suggest that for the majority of the participants' school grounds are an important context to spend time in during weekdays but less so in weekends. Across gender and age it appears that some participants do spend considerable time at school grounds in weekends as indicated by the maximum range. Future analyses are warranted to investigate if this is a specific subgroup behavior of if specific characteristics are present for the used school grounds, e.g. the used school grounds have many facilities or are located close to the users' home. Future context-specific analyses may also investigate correlates or predictors of behaviors more in depth, in particular how the built environment and the perception of the environment more directly is associated with context-specific behaviors.

The number of participants present in different contexts during the WCMC baseline data collection differed considerably by day of week. During weekdays 46.0% of the participants were at playgrounds while almost all participants were in urban green space (95.9%). A similar pattern was found for weekends but with lower percentages; 27% were at playgrounds and 86% were in urban green space. The difference between week and weekend days can be either due to a difference in behaviour, e.g. some participants may never visit playgrounds during weekends, or due to fewer days of weekend day data being included in the analysis, e.g. a mean of 2.5 valid weekdays were included while only a mean of 1.4 valid weekend days were included. These findings may indicate that if the aim is to assess *one* specific behaviour that does not occur frequently, e.g. the use of playgrounds, longer data collection periods may be needed to gather enough information of the specific behaviour. The employed data collection period seems sufficient to assess behaviour in urban green space as 86–96% of the participants spent time in this context with median wear times ranging from 5 to 7 min. Future studies seeking to assess behaviour in only one context should consider to employ a longer data collection period, perhaps including five full days of weekday monitoring (as opposed to four in this study) and four days of weekend monitoring (as opposed to predominantly two in this study). However, this increases both the researcher and participant burden.

Similar to another study using combined accelerometer and GPS data (Maddison et al., 2010), but using a specific context approach as opposed to a buffer based approach as in the Maddison study, it was found that children and adolescent spent the majority of time during weekdays in the school domain. As such, the great emphasis on school interventions to promote PA is legitimized. Recess can be considered as a window of opportunity to increase PA (Ridgers et al., 2010) as recess time is, at least in this study in a Danish context, almost 1 h daily. Another important finding is the extensive use of school grounds outside scheduled school hours during week and weekend days, highlighting the potential and need for open and unrestricted access to school grounds during leisure time.

Although the combination of accelerometer and GPS data is considered optimal in studies aiming to evaluate how the built environment impact PA (Krenn et al., 2011), there are no standards to ensure consistency in the data collection procedures, data processing, analyses or reporting of these data. More cooperation and sharing of protocols on collecting, processing and analysing accelerometer and GPS data would increase comparability. The Global Positioning Systems Health Research Network (www.GPS-HRN.org), data processing systems such as the PALMS-project (2013), and the inclusion of GPS in the planned IPEN Adolescent 19 country collaborative study (www.IPENproject.org) are all important steps towards a greater conformity in this research field, as is the detailed reporting of the WCMC study and methodology in this paper.

Using a combination of accelerometers and GPS to develop context-specific measures has a large potential to lead to new knowledge on physical activity behaviours, inform the development of new interventions, and perhaps later lead to new policies or recommendations for specific subgroups. To be able to measure specific effects of built environment change on physical activity behavior, information on site specific behaviors are needed. To date, a methodology to assess context-specific behavior in a very detailed manner has been lacking, but this study show that it is possible to develop a method that can handle accelerometer and GPS data and provide information on context-specific behaviors. Future studies will use this method in the context of evaluating the effect of changes to the built environment on behavior.

4.1. Strengths and limitations

The WCMC study was designed as a natural experiment to take advantage of large scale changes to the built environment that would not be possible in a more controlled design. We used combined accelerometer and GPS data to be able to assess objective PA and locations of children and adolescent. We developed a methodology based on predefined domains and subdomains to assess context-specific patterns in 15 different contexts. This level of fine contextualization of objectively measured PA activities is one of the first attempts seen in this research field. By presenting baseline results on method efficiency, the numbers of users and time spent in these contexts we have demonstrated the utility of this methodology. Digitizing participant's second homes (for children with parents living separately) or time spent in other homes has the potential to reduce the amount of time spent in other places, however this has to weighed against the time and labour this incurs on the research team. The data collection is more complex, the recruitment of participants harder, and the data processing and complexity of the data is overwhelming when conducting studies based on accelerometer and GPS data. Practical issues of data storage capacity and run times of two-three weeks to generate variables in the database for subsamples of 100 participants were a reality in this study, making the analyses time-consuming and labour-intensive.

This study focused on urban Danish children and as other studies have found differences in the urban/suburban/rural PA patterns (Fairclough et al., 2012; Rainham et al., 2012), the results may not be generalizable to more rural children. The children were not randomly selected as they were selected as part of the WCMC study and all lived within one specific local neighborhood. As such, further studies are needed to confirm the generalizability of the results; in particular during weekends where lower protocol compliance was achieved. Data was collected during early fall and late spring, where daylight and overall weather conditions were quite similar, and the results are possibly not valid during the winter months as weather and season are known to affect behavior (Oreskovic et al., 2012). It is recommended that the methodology in the future is used in a variety of settings, e.g. rural areas, and during various seasons and on different populations to fully understand its use in these settings. Due to sample size it was not possible to compare gender differences within children's and adolescents' groups.

Compared to other studies using combined accelerometer and GPS data (Collins et al., 2012; Cooper et al., 2010; Dessing et al., 2013; Oreskovic et al., 2012; Quigg et al., 2010; Rodriguez et al., 2012; Southward et al., 2012; Wheeler et al., 2010), we chose to use a high inclusion criterion of at least one valid day of 9 h combined data. A 9 h criterion was chosen to retain enough data to be able to conduct a full day pattern analyses. With medium wear times above 11 h a day for the included participants we have accomplished this aim. A criterion of at least one valid day was chosen to retain a reasonable large sample of participants in the study. This might limit the reliability of this study as it has been recommended to collect data from two or more days to gather a reliable estimate of children's activity (Rich et al., 2013).

Steps were taken to increase protocol compliance, for example by gaining teacher support, sending text messages reminders morning and evening, providing phone numbers to contact research staff in case of questions/faulty instruments, and an incentive for complying with the protocol. In future studies it is recommended to employ similar methods to increase compliance. Furthermore, it is recommended to ask participants who do not comply with the protocol to re-wear the equipment to obtain better compliance.

5. Conclusions

The new methodology developed in this study enables objective and precise assessment of PA behaviour for not only children and adolescents, but also a wide range of age groups in specific daily activity contexts. Differences in users of contexts and time spent in contexts between weekdays and weekend days were observed. Lower compliance and lower wear times were observed during weekends. Future studies will evaluate how the implemented changes in the studied neighbourhood influence context-specific behaviours. Results from the WCMC evaluation will advance research on the effects of changes to the built environment on health related behaviours and will be useful in informing planning and health policy.

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Authors' contributions

CDK was the principal investigator of the WCMC study. CDK conceived of and coordinated the study, contributed to acquisition of data, was responsible for analyses, part of the data cleaning, development of the methodology, and drafted the manuscript. JS contributed to the acquisition of data, was responsible for the processing of the GPS, accelerometer and GIS data and the design of the database. MT contributed to the development of the questionnaire and diaries and to complete a pilot test. JK was involved in the PALMS processing and contributed with significant input to the outline of the manuscript. JT helped to conceive of the study, and participated in its design. All authors revised the manuscript critically, and read and approved the final manuscript.

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References

Anon2013. The Physical Activity and Location Measurement (PALMS). [⟨http://ucsd-palms-project.wikispaces.com/⟩].
Adams, M.A., Johnson, W.D., Tudor-Locke, C., 2013. Steps/day translation of the moderate-to-vigorous physical activity guideline for children and adolescents. Int. J. Behav. Nutr. Phys. Act. 10 (49) (available from: PM:23601369).
Andersen, L.B., Riddoch, C., Kriemler, S., Hills, A.P., 2011. Physical activity and cardiovascular risk factors in children. Br. J. Sports Med. 45 (11), 871–876 (available from: PM:21791456).
Bauman, A.E., Reis, R.S., Sallis, J.F., Wells, J.C., Loos, R.J., Martin, B.W., 2012. Correlates of physical activity: why are some people physically active and others not? Lancet 380 (9838), 258–271 (available from: PM:22818938).
Beets, M.W., Beighle, A., Erwin, H.E., Huberty, J.L., 2009. After-school program impact on physical activity and fitness: a meta-analysis. Am. J. Prev. Med. 36 (6), 527–537 (available from: PM:19362799).
Biddle, S.J., Asare, M., 2011. Physical activity and mental health in children and adolescents: a review of reviews. Br. J. Sports Med. 45 (11), 886–895 (available from: PM:21807669).
Bohn-Goldbaum, E.E., Phongsavan, P., Merom, D., Rogers, K., Kamalesh, V., Bauman, A.E., 2013. Does playground improvement increase physical activity among children? A quasi-experimental study of a natural experiment. J. Environ. Public Health 2013 (109841) (available from: PM:23840227).
Chen, K.Y., Basset, D.R., 2005. The technology of accelerometry-based activity monitors: current and future. Med. Sci. Sports Exerc. 37, S490–S500.
Cole, T.J., Bellizzi, M.C., Flegal, K.M., Dietz, W.H., 2000. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 320 (7244), 1240–1243 (available from: PM:10797032).
Colley, R.C., Garriguet, D., Janssen, I., Craig, C.L., Clarke, J., Tremblay, M.S., 2011. Physical activity of Canadian children and youth: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. Health Rep. 22 (1), 15–23 (available from: PM:21510586).
Collins, P., Al-Nakeeb, Y., Nevill, A., Lyons, M., 2012. The impact of the built environment on young people's physical activity patterns: Asuburban–rural comparison using GPS. Int. J. Environ. Res. Public Health 9 (9), 3030–3050 (available from)⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84866921334&partnerID=40&md5=36d132e2967ac9d1eb277d926350a722⟩.
Cooper, A.R., Page, A.S., Wheeler, B.W., Griew, P., Davis, L., Hillsdon, M., Jago, R., 2010. Mapping the walk to school using accelerometry combined with a global positioning system. Am. J. Prev. Med. 38 (2), 178–183 (available from: PM:20117574).
Copenhagen Municipality, 2007. Fælles Boligsocial Helhedsplan for Haraldsgadekvarteret, Københavns Kommune/The City of Copenhagen, Copenhagen.
Danmarks Statistik, 2013. Indvandrere i Danmark 2012, Statistics Denmark, Copenhagen.
Davison, K.K., Lawson, C.T., 2006. Do attributes in the physical environment influence children's physical activity? A review of the literature. Int. J. Behav. Nutr. Phys. Act. 3 (19) (available from: PM:16872543).
de, V.E., de Ridder, D.T., de Wit, J.B, 2011. Environmental correlates of physical activity and dietary behaviours among young people: a systematic review of reviews. Obes. Rev. 12 (5), e130–e142 (available from: PM:20630024).
Dencker, M., Svensson, J., El-Naaman, B., Bugge, A., Andersen, L.B., 2012. Importance of epoch length and registration time on accelerometer measurements in younger children. J. Sports Med. Phys. Fitness 52 (2), 115–121 (available from: PM:22525645).
Dessing, D., Pierik, F.H., Sterkenburg, R.P., van, D.P., Maas, J., De Vries, S.I., 2013. Schoolyard physical activity of 6–11 year old children assessed by GPS and accelerometry. Int. J. Behav. Nutr. Phys. Act. 10, 97 (available from: PM:23945145).
Ding, D., Sallis, J.F., Kerr, J., Lee, S., Rosenberg, D.E., 2011. Neighborhood environment and physical activity among youth a review. Am. J. Prev. Med. 41 (4), 442–455 (available from: PM:21961474).
Evenson, K.R., Catellier, D.J., Gill, K., Ondrak, K.S., McMurray, R.G., 2008. Calibration of two objective measures of physical activity for children. J. Sports Sci. 26 (14), 1557–1565 (available from: PM:18949660).
Fairclough, S.J., Beighle, A., Erwin, H., Ridgers, N.D., 2012. School day segmented physical activity patterns of high and low active children. BMC Public Health 12 (1), 406 (available from: PM:22672654).
Ferreira, I., van der Horst, K., Wendel-Vos, W., Kremers, S., van Lenthe, F.J., Brug, J., 2007. Environmental correlates of physical activity in youth—a review and update. Obes. Rev. 8 (2), 129–154 (available from: PM:17300279).
Floriani, V., Kennedy, C., 2008. Promotion of physical activity in children. Curr. Opin. Pediatr. 20 (1), 90–95 (available from: PM:18197046).
Fremeaux, A.E., Mallam, K.M., Metcalf, B.S., Hosking, J., Voss, L.D., Wilkin, T.J., 2011. The impact of school-time activity on total physical activity: the activitystat hypothesis (EarlyBird 46). Int. J. Obes. (Lond) 35 (10), 1277–1283 (available from: PM:21407175).
Gomersall, S.R., Rowlands, A.V., English, C., Maher, C., Olds, T.S., 2013. The ActivityStat hypothesis: the concept, the evidence and the methodologies. Sports Med 43 (2), 135–149 (available from: PM:23329607).
Guinhouya, B.C., Lemdani, M., Vilhelm, C., Hubert, H., Apete, G.K., Durocher, A., 2009. How school time physical activity is the "big one" for daily activity among schoolchildren: a semi-experimental approach. J. Phys. Act. Health 6 (4), 510–519 (available from: PM:19842466).
Heath, G.W., Parra, D.C., Sarmiento, O.L., Andersen, L.B., Owen, N., Goenka, S., Montes, F., Brownson, R.C., 2012. Evidence-based intervention in physical activity: lessons from around the world. Lancet 380 (9838), 272–281 (available from: PM:22818939).
Jones, A.P., Coombes, E.G., Griffin, S.J., van Sluijs, E.M., 2009. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. Int. J. Behav. Nutr. Phys. Act. 6, 42 (available from: PM:19615073).
Kerr, J., Normam, G., Godbole, S., Raab, F., Demchak, B., Patrick, K., 2012a. Validating GPS data with the PALMS system to detect different active transportation modes. Med. Sci. Sports Exerc. 44, S2529.
Klinker CD, Schipperijn J, Kerr J, Ersbøll AK, Troelsen J, 2014a. Context-specific outdoor time and physical activity among school-children across gender and age: using accelerometers and GPS to advance methods. Front Public Health. 2:20. http://dx.doi.org/10.3389/fpubh.2014.00020. eCollection 2014.
Klinker CD, Schipperijn J, Christian H, Kerr J, Ersbøll AK, Troelsen J, 2014b. Using accelerometers and global positioning system devices to assess gender and age differences in children's school, transport, leisure and home based

physical activity. Int. J. Behav. Nutr. Phys. Act. 11:8. http://dx.doi.org/10.1186/1479-5868-11-8.
Krenn, P.J., Titze, S., Oja, P., Jones, A., Ogilvie, D., 2011. Use of global positioning systems to study physical activity and the environment: a systematic review. Am. J. Prev. Med. 41 (5), 508–515 (available from: PM:22011423).
Lachowycz, K., Jones, A.P., Page, A.S., Wheeler, B.W., Cooper, A.R., 2012. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? Health Place 18 (3), 586–594 (available from: PM:22365385).
Landry, B.W., Driscoll, S.W., 2012. Physical activity in children and adolescents. PM. R 4 (11), 826–832 (available from: PM:23174545).
Maddison, R., Jiang, Y., Vander, H.S., Exeter, D., Mhurchu, C.N., Dorey, E., 2010. Describing patterns of physical activity in adolescents using global positioning systems and accelerometry. Pediatr. Exerc. Sci. 22 (3), 392–407 (available from: PM:20814035).
Niclasen, B., Petzold, M., Schnohr, C.W., 2012. The association between high recreational physical activity and physical activity as a part of daily living in adolescents and availability of local indoor sports facilities and sports clubs. Scand. J. Public Health 40 (7), 614–620 (available from: PM:23042458).
Oreskovic, N.M., Blossom, J., Field, A.E., Chiang, S.R., Winickoff, J.P., Kleinman, R.E., 2012. Combining global positioning system and accelerometer data to determine the locations of physical activity in children. Geospat. Health 6 (2), 263–272 (available from: PM:22639128).
Pedersen, B.K., Andersen, L.B., 2011. Fysisk aktivitet—håndbog om forebyggelse og behandling. Sundhedsstyrelsen/Nat. Board Health.
Pedersen, C.B., 2011. The Danish civil registration system. Scand. J. Public Health 39 (7 Suppl.), 22–25 (available from: PM:21775345).
Quigg, R., Gray, A., Reeder, A.I., Holt, A., Waters, D.L., 2010. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. Prev. Med. 50 (5-6), 235–240 (available from: PM:20153361).
Quigg, R., Reeder, A.I., Gray, A., Holt, A., Waters, D., 2012. The effectiveness of a community playground intervention. J. Urban Health 89 (1), 171–184 (available from: PM:21959697).
Rainham, D.G., Bates, C.J., Blanchard, C.M., Dummer, T.J., Kirk, S.F., Shearer, C.L., 2012. Spatial classification of youth physical activity patterns. Am. J. Prev. Med. 42 (5), e87–e96 (available from: PM:22516507).
Reed, J.A., Hooker, S.P., 2012. Where are youth physically active? A descriptive examination of 45 parks in a southeastern community. Child. Obes 8 (2), 124–131 (available from: PM:22799512).
Rich, C., Geraci, M., Griffiths, L., Sera, F., Dezateux, C., Cortina-Borja, M., 2013. Quality control methods in accelerometer data processing: defining minimum wear time. PLoS One 8 (6), e67206 (available from: PM:23826236).
Riddoch, C.J., Bo, A.L., Wedderkopp, N., Harro, M., Klasson-Heggebo, L., Sardinha, L. B., Cooper, A.R., Ekelund, U., 2004. Physical activity levels and patterns of 9- and 15-yr-old European children. Med. Sci. Sports Exerc. 36 (1), 86–92 (available from: PM:14707773).
Ridgers, N.D., Fairclough, S.J., Stratton, G., 2010. Variables associated with children's physical activity levels during recess: the A-CLASS project. Int. J. Behav. Nutr. Phys. Act. 7, 74 (available from: PM:20937142).
Rodriguez, D.A., Cho, G.H., Evenson, K.R., Conway, T.L., Cohen, D., Ghosh-Dastidar, B., Pickrel, J.L., Veblen-Mortenson, S., Lytle, L.A., 2012. Out and about: association of the built environment with physical activity behaviors of adolescent females. Health Place 18 (1), 55–62 (available from: PM:21945085).
Rowland, T.W., 1998. The biological basis of physical activity. Med. Sci. Sports Exerc. 30 (3), 392–399 (available from: PM:9526885).
Sallis, J.F., Cervero, R.B., Ascher, W., Henderson, K.A., Kraft, M.K., Kerr, J., 2006. An ecological approach to creating active living communities. Annu. Rev. Public Health 27, 297–322 (available from: PM:16533119).
Sallis, J.F., Prochaska, J.J., Taylor, W.C., 2000. A review of correlates of physical activity of children and adolescents. Med. Sci. Sports Exerc. 32 (5), 963–975 (available from: PM:10795788).
Schipperijn, J., Kerr, J., Duncan, S., Madsen, T., Klinker, C.D., Troelsen, J., 2014. Dynamic accuracy of GPS receivers for use in health research: a novel method to assess GPS accuracy in real-world settings. Front. Public Health, 2 (available from).
Sherar, L.B., Griew, P., Esliger, D.W., Cooper, A.R., Ekelund, U., Judge, K., Riddoch, C., 2011. International children's accelerometry database (ICAD): design and methods. BMC Public Health 11, 485 (available from: PM:21693008).
Smith, N.R., Clark, C., Fahy, A.E., Tharmaratnam, V., Lewis, D.J., Thompson, C., Renton, A., Moore, D.G., Bhui, K.S., Taylor, S.J., Eldridge, S., Petticrew, M., Greenhalgh, T., Stansfeld, S.A., Cummins, S., 2012. The Olympic Regeneration in East London (ORiEL) study: protocol for a prospective controlled quasi-experiment to evaluate the impact of urban regeneration on young people and their families. BMJ Open 2 (4) (available from: PM:22936822).
Southward, E.F., Page, A.S., Wheeler, B.W., Cooper, A.R., 2012. Contribution of the school journey to daily physical activity in children aged 11–12 years. Am. J. Prev. Med. 43 (2), 201–204 (available from: PM:22813686).
Tandon, P.S., Saelens, B.E., Zhou, C., Kerr, J., Christakis, D.A., 2013. Indoor versus outdoor time in preschoolers at child care. Am. J. Prev. Med. 44 (1), 85–88 (available from: PM:23253655).
Trost, S.G., Loprinzi, P.D., Moore, R., Pfeiffer, K.A., 2011. Comparison of accelerometer cut points for predicting activity intensity in youth. Med. Sci. Sports Exerc. 43 (7), 1360–1368 (available from: PM:21131873).
Wheeler, B.W., Cooper, A.R., Page, A.S., Jago, R., 2010. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. Prev. Med. 51 (2), 148–152 (available from: PM:20542493).