Supplement Article

Interactions of individual perceived barriers and neighbourhood destinations with obesity-related behaviours in Europe

J. D. Mackenbach[1], J. Lakerveld[1], F. J. Van Lenthe[2], P. J. Teixeira[3], S. Compernolle[4], I. De Bourdeaudhuij[4], H. Charreire[5,6], J.-M. Oppert[5,7], H. Bárdos[8], K. Glonti[9], H. Rutter[9], M. McKee[9], G. Nijpels[10], and J. Brug[1]

[1]Department of Epidemiology and Biostatistics, EMGO Institute for Health and Care Research, VU University Medical Center, Amsterdam, The Netherlands, [2]Department of Public Health, Erasmus Medical Centre Rotterdam, Rotterdam, The Netherlands, [3]Centre for Interdisciplinary Study of Human Performance (CIPER), Faculty of Human Kinetics, University of Lisbon, Lisbon, Portugal, [4]Department of Movement and Sport Sciences, Ghent University, Ghent, Belgium, [5]Equipe de Recherche en Epidámiologie Nutritionnelle (EREN), Centre de Recherche en Epidámiologie et Statistiques, Inserm (U1153), Inra (U1125), Cnam, COMUE Sorbonne Paris Cité, Université Paris 13, Bobigny, France, [6]Paris Est University, Lab-Urba, UPEC, Urban School of Paris, Créteil, France, [7]Sorbonne Universités, Université Pierre et Marie Curie, Université Paris 06; Institute of Cardiometabolism and Nutrition, Department of Nutrition, Pitié-Salpêtrière Hospital, Assistance Publique-Hôpitaux de Paris, Paris, France, [8]Department of Preventive Medicine, Faculty of Public Health, University of Debrecen, Debrecen, Hungary, [9]ECOHOST – The Centre for Health and Social Change, London School of Hygiene and Tropical Medicine, London, UK, and [10]Department of General Practice and Elderly Care, EMGO Institute for Health and Care Research, VU Medical Center Amsterdam, Amsterdam, The Netherlands

Received 14 December 2015; accepted 15 December 2015

Address for correspondence: J.D. Mackenbach, Department of Epidemiology and Biostatistics, EMGO Institute for Health and Care Research, VU University Medical Center, De Boelelaan 1089a, 1081 HV Amsterdam, The Netherlands. E-mail: j.mackenbach@vumc.nl

The copyright line for this article was changed on 30 May 2016 after original online publication

Summary

Perceived barriers towards physical activity and healthy eating as well as local availability of opportunities (destinations in the neighbourhood) are important determinants of obesity-related behaviours in adults. Little is known, however, about how these factors interact with the behaviours.

Data were analysed from 5,205 participants of the SPOTLIGHT survey, conducted in 60 neighbourhoods in urban regions of five different countries across Europe. A virtual audit was conducted to collect data on the presence of destinations in each neighbourhood. Direct associations of, and interactions between, the number of individual perceived barriers and presence of destinations with obesity-related behaviours (physical activity and dietary behaviours) were analysed using multilevel regression analyses, adjusted for key covariates.

Perceiving more individual barriers towards physical activity and healthy eating was associated with lower odds of physical activity and healthy eating. The presence of destinations such as bicycle lanes, parks and supermarkets was associated with higher levels of physical activity and healthier dietary behaviours. Analyses of additive interaction terms suggested that the interaction of destinations and barriers was competitive, such that the presence of destinations influenced obesity-related behaviours most among those perceiving more barriers.

These explorative findings emphasize the interest and importance of combining objective (e.g. virtual neighbourhood audit) methods and subjective (e.g. individual perceived barriers collected in a survey) to better understand how the characteristics of the residential built environment can shape obesity-related behaviours depending on individual characteristics. © 2016 The Authors Obesity Reviews published by John Wiley & Sons Ltd on behalf of International Association for the Study of Obesity (IASO)

Keywords: Built environment, dietary behaviours, physical activity, SPOTLIGHT.

Abbreviations: SES socioeconomic status, BMI body mass index; OR, odds ratio; 95% CI, 95% confidence interval.

obesity reviews (2016) **17** (Suppl. 1), 68–80

Introduction

Socio-ecological models posit (1,2), and empirical evidence shows (3) that obesity-related behaviours, i.e. physical activity, sedentary behaviours and dietary behaviours, are determined by a combination of individual factors and environmental constraints and opportunities. Individual determinants of obesity-related behaviours include psychosocial factors such as motivation, perceived opportunities and barriers, and behavioural norms, in addition to socio-demographic factors such as age, sex and socio-economic factors (4,5). The opportunity to be physically active or eat healthily may depend on the availability, affordability and accessibility of relevant destinations, i.e. destinations where one can be physically active or where healthy or unhealthy foods can be bought or consumed (6). The availability of local places is – to a certain extent – a modifiable aspect of the built environment and therefore amenable to intervention.

The spatial accessibility of shops, services and recreational facilities has been linked to physical activity and primarily walking (7–12), as well as to dietary behaviours (13–19), cardio-metabolic risk factors (20) and coronary heart disease (21). It is possible through urban planning to design where, and how many, destinations are in areas (22). But in order for research findings to be translated into policy and practice, more detailed information is required, particularly regarding specific types of neighbourhood destinations and their influence on obesity-related behaviours. It is likely that different types of destinations exert different influences on physical activity and dietary behaviours. While a high prevalence of destinations in the neighbourhood contributes to a 'walkable' environment and may thus stimulate walking and cycling for transport (23), specific recreational facilities may be more closely related to exercise and sports. The *type* of destination is especially important for the prevalence of food outlets; while the presence of supermarkets where a range of foods – including healthy options such as fruits and vegetables – is readily available may facilitate healthier diets, the presence of fast food outlets has been found to be associated with less-healthy dietary behaviours (16). However, the evidence for associations with specific types of food outlets remains mixed (24), and it is likely that dietary behaviours are influenced in multiple ways by the presence of different food outlets within the local neighbourhood and elsewhere.

Socio-ecological models of health behaviour suggest that built environmental factors can influence obesity-related behaviours directly, possibly moderated by individual characteristics, or indirectly, via psychological mediator processes (2). Environments that facilitate physical activity may motivate individuals (or may require less motivation) to be more physically active (25–27). Similarly, empirical evidence suggests that individuals living in an unhealthy food environment have lower self-efficacy related to eating than individuals living in healthy food environments (28).

However, individuals often perceive barriers to a healthy lifestyle that are independent of the environment, such as lack of motivation or lack of time. Few studies have assessed if the association between presence of destinations and obesity-related behaviours is moderated by individual perceived barriers. This moderation may be synergistic (in that the presence of destinations mainly enables those who perceive few barriers to perform healthy behaviours) or can be competitive (in which case the presence of destinations could stimulate those who perceive many barriers to perform healthy behaviours) (29). There is some evidence for both scenarios in various settings (29–35). For example, a recent three-country study showed that the associations of the environment with leisure-time physical activity were strongest in adults who reported less favourably on psychosocial factors relating to obesity-related behaviours (30).

Whereas previous studies examining interactions between environmental and individual factors have mainly used physical activity as an outcome (29–35), individual and environmental factors are likely to influence both sides of the energy balance equation. Therefore, in this study, we linked neighbourhood destinations and individual factors to both physical activity and dietary behaviours. The aim of this study was to investigate interactions between the presence of destinations in the residential environment and individual perceived barriers to physical activity and healthy eating in relation to obesity-related behaviours.

Methods

Study design and study sample

This study was part of the SPOTLIGHT project (36), conducted in five urban regions in Belgium, France, Hungary, the Netherlands and the UK. Sampling of neighbourhoods and recruitment of participants has been described in detail elsewhere (37). Briefly, neighbourhood sampling was based on a combination of residential density and socio-economic status (SES) data at neighbourhood level. Neighbourhoods were defined according to small-scale local administrative boundaries as used in each country except for Hungary. Budapest is divided into districts and suburbs that are highly heterogeneous in terms of population and much larger than the equivalent administrative areas in the other study countries. In order to ensure comparability between study areas, we defined 1 km^2 areas to represent neighbourhoods in Budapest and suburbs. Across all five locations the average area of a neighbourhood was 1.5 km^2, and the mean population density was 2,700 inhabitants per neighbourhood. Detailed characteristics of the neighbourhoods are described elsewhere (37). Data on residential density were obtained from the Urban Atlas database (European Environment

Agency, 2002) using two categories: high and low residential density (>2/3 and <1/3 of areas covered by residential buildings, respectively). Neighbourhoods were classified as low and high SES on the basis of recent data on neighbourhood median income (i.e. the first and third tertiles, respectively) retrieved from each country's national statistics office. This resulted in four types of neighbourhoods: low SES/low residential density, low SES/high residential density, high SES/low residential density and high SES/high residential density. In each country, three neighbourhoods of each type were randomly sampled (i.e. 12 neighbourhoods per country and 60 neighbourhoods in total). Subsequently, a random sample of adult (age ≥ 18 years) inhabitants was invited to participate in an online survey. The survey contained questions on demographics, neighbourhood perceptions, social environmental factors, health, motivations and barriers for healthy behaviours, obesity-related behaviours and weight and height (to calculate BMI; body mass index). A total of 6,037 (10.8% out of 55,893) individuals participated in the study between February and September 2014. The study was approved by the corresponding local ethics committees of participating countries and all participants to the survey provided informed consent.

Measures

Outcome variables: obesity-related behaviours

Transport-related and leisure-time physical activity were estimated using questions from the International Physical Activity Questionnaire (IPAQ) (38), asking about frequency (number of days in the last seven days) and duration (average time/day) per domain. Good reliability (intra-class correlations range from 0.46 to 0.96), and acceptable criterion validity (median $\rho = 0.30$) has been demonstrated for this questionnaire in a 12-country study (38).

Dietary behaviours were assessed using commonly used food frequency questions (frequency of consumption per week, on a nine-point frequency scale ranging from 'once a week or less' to 'more than twice a day') of fruit, vegetables, fish, sweets, sugar-sweetened beverages and fast food.

Given the non-normal distribution of obesity-related behaviours, we dichotomized outcome consumption variables per week, based on the median: fruit ≥7 times, vegetables ≥7 times, fish ≥2 times, sweets ≥3 times, sweetened beverages ≥2 glasses and fast food ≥2 times. Also based on the median, leisure-time physical activity was dichotomised at ≥25 min per day and transport-related physical activity at ≥30 min per day. These dichotomous outcome measures are referred to in the text as 'low levels' and 'high levels' of the obesity-related behaviours.

Presence of destinations in the residential neighbourhood

Objective environmental data on destinations in the neighbourhood were collected using the validated SPOTLIGHT Virtual Audit Tool (S-VAT) (39). Intra-observer reliability of the tool ranged from 92% agreement (kappa = 0.65) to 100% agreement (kappa = 1.00), and inter-observer reliability ranged from 79% agreement (kappa = 0.44) to 99% agreement (kappa = 0.58). A total number of 4,486 street segments in 59 neighbourhoods (one Hungarian neighbourhood was not covered by Google Street View at the time of the virtual audit) were audited to collect data on the presence of destinations related to physical activity and eating. Street segments were defined as the part of the street between two intersections (with a minimum length of 50 m and a maximum length of 300 m). Using a standard operating procedure, researchers collected data on 40 different items in each street segment (39). 'Destinations' recorded in this audit were indoor recreational facilities, outdoor recreational facilities, public parks, café or bars, takeaway restaurants, fast food restaurants, restaurants, on-street vendors of food, convenience stores, wine or liquor stores, street food markets, local shops and supermarkets. Additionally, we had information on the presence of bicycle lanes. Food outlets were classified according to the food outlet classification of Lake *et al.* (40) Data collection resulted in a database of the characteristics of street segments in each of the audited neighbourhoods. For the present study, we aggregated data on destinations from the street-segment level to the neighbourhood level by taking the percentage of street segments with destinations in the neighbourhood. For example, 'supermarket presence' represents the percentage of street segments in the neighbourhood where at least one supermarket was present.

First, we related the presence of indoor recreational facilities, outdoor recreational facilities, public parks and bicycle paths to physical activity. As earlier studies also indicate that the presence of any type of destinations in the neighbourhood stimulates active transport (and thus physical activity) to these nearby destinations (7–12), we further related an overall 'neighbourhood destinations' variable to physical activity. This variable was created by summing the percentage of street segments in each neighbourhood with each of the key destinations (indoor recreational facilities, outdoor recreational facilities, public parks, cafés or bars, take away restaurants, fast food restaurants, restaurants, on-street food vendors, convenience stores, wine or liquor stores, street food markets, local shops and supermarkets) and taking an unweighted average.

Second, we related the presence of supermarkets and fast food restaurants to several dietary behaviours. These are the two types of food outlets that have most consistently been linked to obesity-related behaviours and obesity (41). In a sensitivity analysis, we also related the presence of local shops, convenience stores and restaurants to dietary behaviours. Although the literature on these specific destinations in relation to dietary behaviours is less consistent, it is reasonable to assume that the presence of bakeries, butchers, convenience stores and restaurants have some influence on dietary behaviours. All neighbourhood destination variables are described in detail in supplementary Table S1.

Previous studies often simply classified destinations as present or absent (42,43) but may ignore the more graded shift from what is accessible and what is not (44). Each neighbourhood destination variable was therefore divided into tertiles (based on the full sample) representing least, medium or greatest presence of destinations. For example, T1 (tertile 1) of 'presence of parks in the neighbourhood' represented the tertile with the fewest parks, while T3 (tertile 3) represented the tertile with the most parks. The only exception is for the presence of fast food restaurants, which was coded reversely because of fast food restaurants' potentially unhealthy influence; T1 comprised neighbourhoods with the fewest fast food restaurants, while T3 comprised neighbourhoods with the most fast food restaurants.

Individual perceived barriers towards physical activity and healthy eating

Seven items from the Neighborhood Quality of Life Study (NQLS, Table S2) (45) were included to assess individual-perceived barriers to regular physical activity (e.g. 'lack of interest in exercise or physical activity', 'lack of time', 'lack of equipment'; Cronbach's alpha = 0.73). Each five-point Likert scale barrier was categorized into *not perceived to be a barrier* ('never' or 'rarely') and *perceived to be a barrier* ('sometimes', 'often' or 'very often'). A categorical variable 'number of perceived physical activity barriers' was created by summing the number of barriers per individual, and then categorizing the number of barriers into 0 ('none' (10% of the sample), 1–3 ('few'; 54% of the sample) and 4–7 ('many'; 36% of the sample).

Barriers to healthy eating were derived from the pan-European consumer attitudinal study (e.g. 'busy lifestyle' and 'price') and consisted of 10 items (Table S2) (46). The two last items (containing double denials) were discarded as participants reported these items to be confusing. The reliability of the eight remaining items was high (alpha = 0.80). Each five-point Likert scale barrier was categorized into *not perceived to be a barrier* ('never' or 'rarely') and *perceived to be a barrier* ('sometimes', 'often' or 'very often'). A variable 'number of healthy eating barriers' was subsequently created by summing the number of barriers per individual, and then categorizing the number of barriers into 0 ('none'; 26% of the sample), 1–3 ('few'; 45% of the sample) and 4–8 ('many'; 29% of the sample).

Table S2 describes the mean scores and reliability of individual perceived barriers.

Covariates

Information on age, gender, employment status (yes, no), household composition (number of adults and children in the household) and educational level was collected in the survey. As education systems differed between countries, we divided self-reported education levels into 'higher education' (college or university level) and 'lower education' (from less than primary to higher secondary education).

Statistical analyses

After exclusion of individuals who could not be allocated to one of the 59 selected neighbourhoods ($n = 732$), a sample of 5,205 participants was available for analyses. Differences in characteristics of individuals perceiving none, few and many barriers are examined using ANOVA and chi-Square tests.

As item non-response ranged from <1% (age) to 26% (individual perceived barriers), complete case analysis was likely to result in biased estimates (47). Assuming that data were missing at random (i.e. the probability that a variable value is missing depends on other data that are observed in the dataset but not on any of the missing values), multiple imputations were performed. Given the percentage of missing values, 30 imputed datasets were generated, as recommended by Rubin (48) and Bodner (49). Missing values were imputed using Predictive Mean Matching in SPSS version 22.0. All variables described in the methods section were entered in the imputation models (50).

Multilevel multivariable logistic regression models with random intercepts were used to explore the associations of number of individual perceived barriers and presence of destinations with obesity-related behaviours of participants (Level 1) nested within neighbourhoods (Level 2). All associations were adjusted for age, gender, education, employment status and household composition. As availability of destinations and residential density tend to coexist (11), and our analyses (not shown) also demonstrated that presence of destinations was significantly higher in neighbourhoods with high residential density, we additionally adjusted the analyses with 'presence of destinations' as independent variable for residential density. All destinations were examined in separate models to avoid multicollinearity.

We explored multiplicative interactions between the two main effects by adding an interaction term to the models. We subsequently explored additive interactions, whereby each neighbourhood destination–individual barrier interaction term was added separately to the model. Because additive interactions are considered more intuitive and relevant to public health (51), additive interaction terms were also calculated if multiplicative interactions were not statistically significant. However, to avoid the risk of multiple testing, additive interactions were only explored where there were significant associations with both individual perceived barriers and presence of destinations. Finally, we calculated the relative excess risk due to interaction (RERI) to quantify interaction on the additive scale. The RERI is a measure of interaction between two parameters with a value further away from zero indicating stronger interaction. The tool created by Knol *et al.* was used to calculate the RERI and the accompanying 95% confidence interval (CI) (52,53).

Results

Tables 1 and 2 describe characteristics of participants perceiving no, few or many barriers to physical activity and healthy eating. Participants perceiving many barriers to physical activity were on average younger, male and less well educated than those perceiving few or no barriers. They also had a higher mean BMI and were less physically active. Similarly, those perceiving many barriers to healthy eating were younger, had a higher mean BMI and had fewer healthy eating behaviours; they consumed less fruit, vegetables, and fish, and more sweets, sugar-sweetened beverages and fast food.

Table 3 shows associations of presence of destinations in the neighbourhood with levels of physical activity. Participants having fewer parks in the neighbourhood (T1) had 25% lower odds of having high levels of leisure-time physical activity (OR = 0.75, 95%CI = 0.62; 0.90). Further, having fewer indoor recreational facilities present was associated with lower odds of transport-related physical activity, having fewer outdoor recreational facilities present was associated with lower odds of leisure-time physical activity, and having

Table 1 Characteristics of participants perceiving no, few or many barriers towards physical activity

	zero perceived barriers towards physical activity (*N* = 423)	1–3 perceived barriers towards physical activity (*N* = 2,327)	4–7 perceived barriers towards physical activity (*N*–1,526)	F or χ^2 statistic (*p*-value)	*p*-value
Age (mean (SD))	57.4 (14.8)^{2,3}	51.5 (15.6)^{1,3}	48.2 (16.0)^{1,2}	60.5	<0.001
Body mass index (mean (SD))	24.4 (3.6)^{3}	24.9 (4.3)^{3}	25.8 (5.0)^{1,2}	24.1	<0.001
Gender (% men)	48.0%	54.1%	57.6%	13.0	0.001
Education (% high)	54.1%	61.0%	49.3%	51.1	<0.001
Minutes leisure-time physical activity/day (mean (SD))	63.1 (55.3)^{2,3}	40.6 (46.1)^{1,3}	31.2 (41.1)^{1,2}	83.7	<0.001
Minutes transport-related physical activity/day (mean (SD))	59.7 (53.0)^{2,3}	45.1 (46.9)^{1,3}	40.4 (47.7)^{1,2}	27.1	<0.001

Descriptive characteristics are presented for the non-imputed data. *SD* = standard deviation.
[1]indicates that the mean value differs from the first group (0 perceived barriers),
[2]indicates that the mean value differs from the second group (1–3 perceived barriers) and
[3]indicates that the mean value differs from the third group (4–7 perceived barriers).

Table 2 Characteristics of participants perceiving no, few or many barriers towards healthy eating

	zero perceived barriers towards healthy eating (*N* = 1098)	1–3 perceived barriers towards healthy eating (*N* = 1897)	4–8 perceived barriers towards healthy eating (*N* = 1246)	F or χ^2 statistic (*p*-value)	*p*-value
Age (mean years (*SD*))	59.0 (14.9)^{2,3}	50.6 (15.7)^{1,3}	44.8 (14.5)^{1,2}	256.3	<0.001
Body mass index (mean (*SD*)	24.6 (3.7)^{3}	25.0 (4.4)^{3}	25.8 (5.0)^{1,2}	23.6	<0.001
Gender (% men)	46.30%	45.90%	43.40%	2.4	0.30
Education (% high)	52.70%	60.00%	52.70%	22.6	<0.001
Fruit consumption/week (mean (*SD*))	8.1 (4.9)^{2,3}	7.0 (5.0)^{1,3}	5.9 (4.6)^{1,2}	61.6	<0.001
Vegetable consumption/week (mean (*SD*))	7.6 (3.5)^{2,3}	7.1 (3.6)^{1,3}	6.4 (3.7)^{1,2}	34.8	<0.001
Fish consumption/week (mean (*SD*))	1.4 (1.2)^{2,3}	1.2 (1.1)^{1,3}	1.1 (1.1)^{1,2}	27.4	<0.001
Sweets consumption/week (mean (*SD*))	3.3 (3.0)^{2,3}	3.8 (3.3)^{1}	3.7 (3.2)^{1}	9.5	<0.001
Glasses sweetened beverages/week (mean (*SD*))	3.0 (3.9)^{2,3}	3.6 (4.6)^{1,3}	4.4 (5.1)^{1,2}	27.0	<0.001
Fast food consumption/week (mean (*SD*))	0.6 (0.4)^{2,3}	0.6 (0.5)^{1,3}	0.7 (0.7)^{1,2}	20.5	<0.001

Descriptive characteristics are presented for the non-imputed data. *SD* = standard deviation.
[1]indicates that the mean value differs from the first group (0 perceived barriers),
[2]indicates that the mean value differs from the second group (1–3 perceived barriers) and
[3]indicates that the mean value differs from the third group (4–7 perceived barriers).

Table 3 Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses between the exposure of interest and physical activity outcome measures (*N* = 5205)

		Leisure-time physical activity ≥25 min/day		Transport-related physical activity ≥30 min/day	
		OR	95% CI	OR	95% CI
Presence of parks	T3 (most)	*REF*		*REF*	
	T2	0.97	0.81; 1.16	1.04	0.80; 1.47
	T1 (least)	**0.75**	0.62; 0.90	1.09	0.80; 1.41
Presence of indoor recreational facilities	T3 (most)	*REF*		*REF*	
	T2	0.97	0.68; 1.40	1.02	0.59; 1.75
	T1 (least)	0.89	0.73; 1.07	**0.71**	0.53; 0.93
Presence of outdoor recreational facilities	T3 (most)	*REF*		*REF*	
	T2	0.95	0.77; 1.17	1.03	0.75; 1.41
	T1 (least)	**0.82**	0.68; 0.98	0.77	0.58; 1.01
Presence of bicycle lanes	T3 (most)	*REF*		*REF*	
	T2	1.19	0.97; 1.44	1.11	0.83; 1.49
	T1 (least)	1.12	0.93; 1.36	**0.73**	0.55; 0.97

Bold values indicate significant odds ratios. REF = reference category. All models are adjusted for age, gender, education, household composition, employment status and neighbourhood residential density.

fewer bicycle lanes present was associated with lower odds of transport-related physical activity. The overall neighbourhood destinations score (presence of any non-residential destinations) was not associated with leisure-time physical activity (OR for T3 = 0.93, 95% CI = 0.76; 1.15) or transport-related physical activity (OR for T3 = 1.08, 95% CI = 0.78; 1.48).

Participants perceiving more barriers were less likely to report high levels of physical activity. For example, participants perceiving many (4–7) barriers had 73% lower odds of engaging in high levels of leisure-time physical activity than participants perceiving no barriers towards physical activity. Similar patterns were observed when transport-related physical activity was the outcome variable (Table 4).

Table 5 shows the associations of the presence of supermarkets and fast food restaurants with dietary behaviours. Having fewer supermarkets in the neighbourhood (T1) was associated not only with lower levels of vegetable and fish consumption but also with lower levels of fast food consumption. Individuals living in neighbourhoods with more fast food restaurants present (T1) had higher consumption of sugar-sweetened beverages and fast food as well as higher vegetable and fish consumption. Table S3 shows the associations between dietary behaviours and the presence of local shops, convenience stores and restaurants.

Table 6 shows that individuals perceiving more barriers to healthy eating were less likely to consume high levels of fruit, vegetable and fish, and more likely to consume high levels of sweets, sugar-sweetened beverages and fast food. For example, individuals perceiving many (4–8) barriers to healthy eating were more than three times more likely to have high levels of fast food consumption than those who perceived fewer barriers.

Multiplicative interaction terms for individual perceived barriers and presence of destinations were not statistically significant for any of the outcomes variables (data not shown).

In contrast, additive interaction terms indicated that both the presence of destinations and perceived barriers had both independent and joint effects on obesity-related behaviours (shown in Tables 7 and 8).

Among those living in a neighbourhood with the fewest parks, individuals perceiving many barriers to physical activity were 80% less likely to engage in high levels of leisure-time physical activity than those perceiving no barriers (Table 7a). Similarly, among those individuals living

Table 4 Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses between the potential effect modifier and physical activity outcome measures (*N* = 5205)

		Leisure-time physical activity ≥25 min/day		Transport-related physical activity ≥30 min/day	
		OR	95% CI	OR	95% CI
Number of individual perceived barriers	zero	*REF*		*REF*	
towards physical activity	1–3	**0.43**	0.34; 0.54	**0.67**	0.53; 0.84
	4–7	**0.27**	0.21; 0.35	**0.53**	0.42; 0.67

Bold values indicate significant odds ratios. OR = odds ratio. All models are adjusted for age, gender, education, household composition, and employment status.

Table 5 Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses between the exposure of interest and dietary behaviour outcome measures (*N* = 5205)

		fruit consumption ≥7 times a week		vegetable consumption ≥7 times a week		fish consumption ≥2 times a week		sweets consumption ≥3 times a week		sugar-sweetened beverage consumption ≥2 glasses a week		fast food consumption ≥2 times a week	
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Presence of supermarkets	T3 (most)	*REF*		*REF*		*REF*		*REF*		*REF*		*REF*	
	T2	1.04	0.86; 1.27	1.19	0.81; 1.74	0.86	0.52; 1.45	**1.40**	1.02; 1.92	1.21	0.90; 1.63	**0.63**	0.42; 0.95
	T1 (least)	0.93	0.76; 1.15	**0.59**	0.40; 0.88	**0.52**	0.31; 0.88	1.06	0.76; 1.47	0.77	0.57; 1.04	**0.50**	0.32; 0.80
Presence of fast food restaurants	T3 (least)	*REF*		*REF*		*REF*		*REF*		*REF*		*REF*	
	T2	1.00	0.73; 1.38	1.58	0.84; 2.95	1.73	0.84; 3.58	0.73	0.43; 1.22	0.98	0.61; 1.58	**1.79**	1.22; 2.63
	T1 (most)	1.16	0.97; 1.38	**1.52**	1.05; 2.21	**2.58**	1.64; 4.06	0.85	0.63; 1.15	**1.36**	1.03; 1.79	**2.10**	1.10; 4.03

Bold values indicate significant odds ratios. OR = odds ratio. All models are adjusted for age, gender, education, household composition, employment status and neighbourhood residential density.

Table 6 Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses between the potential effect modifier and dietary behaviour outcome measures (*N* = 5205)

		fruit consumption ≥7 times a week		vegetable consumption ≥7 times a week		fish consumption ≥2 times a week		sweets consumption ≥3 times a week		sugar-sweetened beverage consumption ≥2 glasses a week		fast food consumption ≥2 times a week	
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Number of individual perceived barriers towards healthy eating	zero (ref)	—		—		—		—		—		—	
	1–3	**0.63**	0.53; 0.74	**0.54**	0.46; 0.65	**0.73**	0.62; 0.85	**1.36**	1.17; 1.59	**1.22**	1.04; 1.43	**1.87**	1.18; 2.96
	4–8	**0.41**	0.34; 0.49	**0.32**	0.27; 0.39	**0.56**	0.46; 0.68	**1.41**	1.18; 1.69	**1.61**	1.33; 1.95	**3.09**	1.94; 4.91

Bold values indicate significant odds ratios. OR–odds ratio. All models are adjusted for age, gender, education, household composition, and employment status. Perceiving zero barriers towards physical activity (zero) served as the reference category (ref).

Table 7 a–d. Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses describing the effect modification of individual perceived barriers in the association between the exposure of interest and levels of leisure-time physical activity (≥25 min/day) and transport-related physical activity (≥30 min/day). *N* = 5205

7a. Presence of park – leisure-time physical activity	T3 (most parks)	T2	T1 (least parks)
RERI (95%CI) = 0.27 (−0.10; 0.65)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.00 (0.55; 1.82)	0.65 (0.38; 1.11)
1–3 barriers	**0.39 (0.26; 0.60)**	**0.41 (0.26; 0.64)**	**0.31 (0.20; 0.47)**
4–7 barriers	**0.27 (0.18; 0.42)**	**0.23 (0.15; 0.36)**	**0.19 (0.12; 0.30)**
7b. Presence of outdoor recreational facilities – leisure-time physical activity	T3 (most facilities)	T2	T1 (least facilities)
RERI (95%CI) = **0.20** *(0.02; 0.39)*	OR (95%CI)	OR (95%CI)	OR (95%CI)
0 barriers	1.00 (ref)	1.12 (0.61; 2.05)	0.76 (0.46; 1.24)
1–3 barriers	**0.42 (0.29; 0.60)**	**0.43 (0.28; 0.64)**	**0.36 (0.24; 0.53)**
4–7 barriers	**0.28 (0.19; 0.42)**	**0.22 (0.15; 0.35)**	**0.24 (0.16; 0.36)**
7c. Presence of indoor recreational facilities - transport-related physical activity	T3 (most facilities)	T2	T1 (least facilities)
RERI (95%CI) = 0.10 (−0.28; 0.49)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.96 (0.70; 5.52)	0.66 (0.40; 1.10)
1–3 barriers	**0.63 (0.43; 0.95)**	0.70 (0.36; 1.38)	**0.49 (0.31; 0.77)**
4–7 barriers	**0.59 (0.40; 0.89)**	**0.37 (0.17; 0.79)**	**0.36 (0.23; 0.58)**
7d. Presence of bicycle lane - transport-related physical activity	T3 (most bicycle lanes)	T2	T1 (least bicycle lanes)
RERI (95%CI) = −0.21 (−0.79; 0.38)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.68 (0.94; 3.00)	0.99 (0.58; 1.69)
1–3 barriers	0.91 (0.61; 1.34)	0.87 (0.55; 1.38)	**0.64 (0.41; 1.02)**
4–7 barriers	**0.67 (0.45; 1.01)**	0.81 (0.51; 1.31)	**0.45 (0.29; 0.72)**

Bold values indicate significant odds ratios. OR = odds ratio. All models are adjusted for age, gender, education, household composition, employment status and neighbourhood residential density.

in a neighbourhood with few bicycle lanes, individuals perceiving many barriers to physical activity were 55% less likely to engage in high levels of transport-related physical activity than those perceiving no barriers. However, individuals perceiving no barriers and living in a neighbourhood with few bicycle lanes did not have significantly lower odds of engaging in high levels of transport-related physical activity than individuals living in a neighbourhood with many bicycle lanes (Table 7d).

Table 8a–h and Table S4a–e show the results of the additive interaction effects of food outlets with perceived-individual barriers in relation to dietary behaviours. Individuals perceiving no barriers to healthy eating and living in neighbourhoods with few supermarkets (T1) had 40% lower odds of having high levels of vegetable consumption than individuals living in a neighbourhood with many supermarkets (Table 8a). Living in a neighbourhood with many supermarkets but perceiving many barriers to healthy eating was also associated with lower odds (OR = 0.33) of high-level vegetable consumption. Individuals in neighbourhoods with few supermarkets, ánd perceiving many barriers were worst off: they had an 81% lower odds of having high levels of vegetable consumption. The same pattern was observed with fish consumption as outcome (Table 8b). A number of RERIs were statistically significant, indicating that the joint effect of individual-perceived barriers and objective presence of destinations was greater than the sum of the two single effects.

Discussion

This cross-European study demonstrated that individual perceived barriers, as well as the presence of objectively measured destinations in the residential neighbourhood, are significant correlates of physical activity and dietary behaviours. Moreover, we found that individual barriers moderated the associations between neighbourhood destinations and obesity-related behaviours.

As expected from behaviour-change theory and from previous studies (54), individuals perceiving many barriers to physical activity and healthy eating showed less favourable obesity-related behaviours than individuals perceiving few or no barriers to physical activity and healthy eating. Individual perceived barriers to physical activity were somewhat less strongly associated with transport-related physical activity than with leisure-time physical activity. This may be because choosing to perform leisure-time physical activity requires a conscious decision, while transport-related physical activity such as commuting to work can be part of a daily routine. Alternatively, it may be that the questions regarding barriers to 'regular physical activity' were interpreted as barriers to leisure-time physical activity. For dietary behaviours, strongest associations were found between number of individual perceived barriers and levels of vegetable and fast food consumption.

Consistent with previous literature (7–15), we found associations with destinations that could specifically be linked to

Table 8 a–h. Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses describing the effect modification of individual perceived barriers in the association between the exposure of interest and levels of fruit consumption (≥7 times/week), vegetable consumption (≥7 times/week), fish consumption (≥2 times/week), sweets consumption (≥3 times/week), sugar-sweetened beverage consumption (≥2 glasses/week) and fast food consumption (≥2 times/week). *N* = 5205

8a. Presence of supermarkets – high vegetable consumption	T3 (most supermarkets)	T2	T1 (least supermarkets)
RERI (95% CI) = 0.26 (−0.04; 0.57)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.18 (0.70; 1.97)	**0.60 (0.36; 1.01)**
1–3 barriers	**0.61 (0.44; 0.85)**	**0.60 (0.37; 0.96)**	**0.32 (0.19; 0.51)**
4–7 barriers	**0.33 (0.24; 0.47)**	**0.39 (0.23; 0.64)**	**0.19 (0.12; 0.32)**
8b. Presence of supermarkets – high fish consumption	T3 (most supermarkets)	T2	T1 (least supermarkets)
RERI (95% CI) = **0.37** *(0.14; 0.60)*	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	0.67 (0.37; 1.21)	**0.42 (0.23; 0.78)**
1–3 barriers	**0.63 (0.45; 0.87)**	**0.51 (0.29; 0.91)**	**0.32 (0.17; 0.58)**
4–7 barriers	**0.46 (0.32; 0.64)**	**0.43 (0.23; 0.79)**	**0.25 (0.13; 0.46)**
8c. Presence of supermarkets – high sweets consumption	T3 (most supermarkets)	T2	T1 (least supermarkets)
RERI (95% CI) = −0.31 (−1.03; 0.41)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	**1.80 (1.17; 2.77)**	1.38 (0.88; 2.16)
1–3 barriers	**1.62 (1.19; 2.20)**	**2.52 (1.65; 3.84)**	**1.64 (1.06; 2.52)**
4–7 barriers	**1.83 (1.33; 2.53)**	**2.06 (1.31; 3.24)**	**1.90 (1.22; 2.95)**
8d. Presence of supermarkets – high fast food consumption	T3 (most supermarkets)	T2	T1 (least supermarkets)
RERI (95% CI) = −2.28 (−5.60; 1.04)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	0.86 (0.26; 2.86)	1.10 (0.35; 3.39)
1–3 barriers	**2.53 (1.01; 6.37)**	1.96 (0.73; 5.23)	1.20 (0.43; 3.36)
4–7 barriers	**4.38 (1.75; 10.93)**	**2.69 (1.01; 7.16)**	2.19 (0.80; 6.02)
8e. Presence of fast food restaurants – high vegetable consumption	T3 (least fast food restaurants)	T2	T1 (most fast food restaurants)
RERI (95% CI) = −0.18 (−0.80; 0.42)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.55 (0.86; 2.23)	1.39 (0.86; 2.23)
1–3 barriers	**0.52 (0.42; 0.65)**	0.76 (0.38; 1.55)	0.85 (0.56; 1.29)
4–7 barriers	**0.30 (0.23; 0.38)**	**0.64 (0.31; 1.32)**	**0.49 (0.32; 0.76)**
8f. Presence of fast food restaurants – high fish consumption	T3 (least fast food restaurants)	T2	T1 (most fast food restaurants)
*RERI (95% CI) = −***1.15** *(−2.24; −0.05)*	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.26 (0.52; 3.06)	**2.98 (1.77; 5.01)**
1–3 barriers	**0.73 (0.60; 0.89)**	1.42 (0.64; 3.14)	**1.92 (1.17; 3.14)**
4–7 barriers	**0.58 (0.45; 0.75)**	1.14 (0.50; 2.59)	1.41 (0.85; 2.35)
8g. Presence of fast food restaurants – high SSB consumption	T3 (least fast food restaurants)	T2	T1 (most fast food restaurants)
RERI (95% CI) = 0.17 (−0.50; 0.84)	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	0.89 (0.42; 1.85)	1.39 (0.93; 2.09)
1–3 barriers	**1.24 (1.01; 1.51)**	1.16 (0.63; 2.12)	**1.63 (1.13; 2.33)**
4–7 barriers	**1.60 (1.25; 2.05)**	1.61 (0.84; 3.06)	**2.17 (1.49; 3.16)**
8h. Presence of fast food restaurants - high fast food consumption	T3 (least fast food restaurants)	T2	T1 (most fast food restaurants)
RERI (95% CI) = **2.60** *(0.80; 4.40)*	OR (95% CI)	OR (95% CI)	OR (95% CI)
0 barriers	1.00 (ref)	1.73 (0.37; 8.16)	0.50 (0.15; 1.72)
1–3 barriers	1.25 (0.71; 2.20)	**2.81 (1.10; 7.18)**	**2.30 (1.22; 4.36)**
4–7 barriers	**1.94 (1.08; 3.15)**	**3.56 (1.45; 8.75)**	**4.05 (2.17; 7.55)**

Bold values indicate significant odds ratios. OR = odds ratio. SSB = sugar-sweetened beverage. All models are adjusted for age, gender, education, household composition, employment status and neighbourhood type.

physical activity (such as the presence of parks and outdoor recreational facilities) and no associations between the presence of 'any type of destination' and physical activity. This suggests that research focusing on the associations between destinations and physical activity may benefit from behavioural specificity: in order to translate scientific findings into interventions or policies, 'determinants' of behaviour should be as close as possible to the studied behaviour (55). Previous studies that found an association between the presence of general destinations with physical activity may have been confounded by residential density (11,56). Indeed, while findings from the International Physical Activity and Environment Network (IPEN) study showed that close proximity to several local destinations was associated with BMI, the authors concluded that this may be due to the compactness of these neighbourhoods (57).

However, studying the associations between presence of destinations and dietary behaviours may require a different approach. Having more supermarkets present in the residential neighbourhood was associated not only with higher vegetable and fish consumption but also with higher fast food consumption. Similarly, more fast food restaurants in the neighbourhood was associated with higher vegetable, fish and fast food consumption. Although we adjusted for residential density, it is possible that the presence of fast food restaurants is a proxy for the presence of both 'healthy' (supermarkets) and 'unhealthy' (fast food restaurants) destinations. Some evidence for such an interaction between different food outlets was provided by Burgoine *et al.*, showing that associations between exposure to fast food outlets and fast food consumption were only significant once adjusted for exposure to other food outlets (58). This adds to the notion that, rather than a few critical environmental characteristics being strongly associated with dietary behaviours, there appears to be a cumulative effect of both negative and positive environmental factors. Further, destinations in the residential neighbourhood may not be the destinations that individuals actually visit (for example, because they do their grocery shopping near their work place (59), and other factors, such as price (60), may be important as well. Contradictory results may also be due to multiple testing, or due to the crude measure of presence of destinations in the neighbourhood. Our approach using tertiles suggests that having more parks, recreational facilities or supermarkets is better for physical activity and healthy eating. This is preferred over an approach that classifies destinations as present or absent, as it allows for a more graded shift from what is accessible and what is not. Yet, the marginal difference of additional supermarkets in addition to at least one may be minimal, whereas multiple recreational facilities may support physical activity in a more incremental way.

Our main results showed that individual barriers moderated the associations between neighbourhood destinations and obesity-related behaviours. That is, obesity-related behaviours were least favourable in individuals who perceived many barriers to healthy behaviours and who had few destinations in their neighbourhood. The competitive mechanism was clearly favoured in our results, indicating that the influence of the environment (presence of destinations) was greatest in individuals perceiving many barriers. We did not find evidence for a synergetic mechanism, whereby the influence of the environment is greatest in individuals perceiving few barriers. Rather, we found that the presence of destinations was not associated with obesity-related behaviours in those perceiving no barriers to healthy behaviours. This is in line with previous studies (29–35,61,62) and calls for a more sophisticated approach to studying the built environment, taking into account different subgroups. Future studies could also examine so-called 'hidden interactions', in which case the main effects of the built environment-behaviour associations are not statistically significant. Testing for such interactions may reveal that the built environment is related to obesity-related behaviours in some groups, but not in others.

Methodological considerations

The main limitation of this study is the cross-sectional design, which has a number of implications. The associations between perceived individual barriers and obesity-related behaviours may suffer from same-source bias: it may be that individuals with less-favourable obesity-related behaviours adjust their beliefs to match their actions, in order to avoid cognitive dissonance (63). Similarly, any observed associations between the presence of destinations and obesity-related behaviours may be due to residential self-selection; that is, individuals may select their area of residence based on their health behaviour (64,65). Additionally, although we hypothesized that associations between the presence of destinations in the neighbourhood with obesity-related behaviours would be moderated by individual perceived barriers, it is not possible to reach a definitive conclusion on any 'moderator role' of individual perceived barriers because of the cross-sectional nature of this study. It may be that when there are ample opportunities to be physically active, individuals may become more motivated (or may need less motivation) to perform physical activity (26,27). Finally, objective data on the presence of destinations was collected using a virtual audit tool in Google Street View. Images depicted often did not reflect the built environment in 2014 (the year in which the survey was conducted). Despite this limitation, the use of virtual audits using remote imaging (such as Google Street View) has proven to be as valid and reliable as street audits (39,66).

Two other important limitations are the low response rate and the use of self-report questionnaires. The use of self-report data on obesity-related behaviours may have led to misclassification and same-source bias, especially because we were unable to dichotomize these variables based on current guidelines. Low response rates (10.1% in this study) are increasingly common in large surveys; this is likely to have led to the inclusion of a selective group of participants. As the study was conducted among residents of neighbourhoods in large urban areas across five European countries, the results cannot be directly generalized to other settings. Fourth, our study design prevented us from isolating the effect of destinations from other built environmental factors. This is especially important as the presence of destinations may be a proxy for other environmental factors (56). We did however adjust our analyses for high or low residential density, as availability of destinations and residential density tends to coexist (11).

There are several strengths to this study. First, we objectively measured the presence of destinations in the neighbourhood using a validated tool (39). Previous studies using neighbourhood perceptions instead of objective measures of the neighbourhood environment may have suffered from same-source bias as people who are physically active are more likely to be aware of their neighbourhood.

Another strength was that the study was undertaken in different European countries, which increases the external validity of our findings. We also addressed both sides of the energy balance equation: physical activity and dietary behaviours. Lastly, we measured individual perceived barriers that were specifically related to physical activity and healthy eating, rather than barriers to a healthy lifestyle in general. This addresses the ecological model principle of behavioural specificity (55).

Conclusions

This cross-European study explored interactions between the built environment and individual perceived barriers for explaining higher and lower levels of obesity-related behaviours. The results confirm the importance of residential destinations for obesity-related behaviours and emphasize the interest and importance of combining objective (such as the use of a virtual audit) and subjective methods (such as perceptions measured in a survey) better to understand how the characteristics of the residential built environment can shape obesity-related behaviours depending on individual factors.

Perceiving individual barriers towards physical activity and healthy eating was strongly associated with physical activity and several dietary behaviours. Additionally, we showed that such barriers amplify the associations of the presence of neighbourhood destinations with obesity-related behaviours. Intervention studies could assess whether individuals perceiving many barriers indeed benefit most from urban design that invites healthy behaviours, and observational studies could describe the characteristics of groups that perceive multiple barriers to healthy behaviours. Nonetheless, this study is another documentation of the importance of providing walkable environments with good spatial accessibility to shops, services and recreational facilities, where people have the opportunity to be more physically active and eat healthily.

Declaration of interests

The authors have no conflicts of interest to declare.

Acknowledgements

The SPOTLIGHT project was funded by the Seventh Framework Programme (CORDIS FP7) of the European Commission, HEALTH (FP7-HEALTH-2011-two-stage), grant agreement no. 278186. The content of this article reflects only the authors' views, and the European Commission is not liable for any use that may be made of the information contained therein.

Supporting information

Additional Supporting Information may be found in the online version of this article, http://dx.doi.org/10.1111/obr.12374

Table S1. Measurement of destinations present in the neighbourhood.
Table S2. Measurement of individual perceived barriers towards physical activity and healthy eating.
Table S3. Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses between the exposure of interest and dietary behaviours outcome measures ($N = 5205$).
Table S4a–e. Odds ratios (OR) and 95% confidence intervals (95% CI) as derived from multilevel regression analyses describing the effect modification of individual perceived barriers in the association between the exposure of interest and levels of fruit consumption, (≥7 times/week), fish consumption, (≥2 times/week), sweet consumption, (≥3 times/week) and fast food consumption (≥2 times/week). $N = 5205$.

References

1. Egger G, Swinburn B. An 'ecological' approach to the obesity epidemic. *BMJ* 1997; **315**: 477–480.
2. Kremers SPJ, de Bruijn GJ, Visscher TLS *et al*. Environmental influences on energy balance-related behaviors: A dual-process view. *Int J Behav Nutr Phys Act* 2006; **3**: 9.
3. Pouliou T, Elliott SJ. Individual and socio-environmental determinants of overweight and obesity in Urban Canada. *Health Place* 2010; **16**: 389–398.
4. Sobal J, Stunkard AJ. Socioeconomic status and obesity: a review of the literature. *Psychol Bull* 1989; **105**: 260–275. URL http://www.ncbi.nlm.nih.gov/pubmed/2648443.
5. Teixeira PJ, Carraça EV, Marques MM *et al*. Successful behavior change in obesity interventions in adults: a systematic review of self-regulation mediators. *BMC Med* 2015; **13**: 1–16. DOI: 10.1186/s12916-015-0323-6.
6. Sallis JF, Glanz K. Physical activity and food environments: solutions to the obesity epidemic. *Milbank Q* 2009; **87**: 123–154. DOI: 10.1111/j.1468-0009.2009.00550.x.
7. Karusisi N, Thomas F, Méline J *et al*. Environmental conditions around itineraries to destinations as correlates of walking for transportation among adults: The RECORD cohort study. *PLoS One* 2014; **9**. DOI: 10.1371/journal.pone.0088929.
8. Koohsari MJ, Sugiyama T, Lamb KE *et al*. Street connectivity and walking for transport: role of neighborhood destinations. *Prev Med (Baltim)* 2014; **66**: 118–122. DOI: 10.1016/j.ypmed.2014.06.019.
9. Kerr J, Emond JA, Badland H *et al*. Perceived neighborhood environmental attributes associated with walking and cycling for transport among adult residents of 17 cities in 12 countries: the IPEN study. *Environ Health Perspect* 2015; epub. DOI: 10.1289/ehp.1409466.

10. Ribeiro AI, Pires A, Carvalho MS *et al*. Distance to parks and non-residential destinations influences physical activity of older people, but crime doesn't: a cross-sectional study in a southern European city. *BMC Public Health* 2015; **15**: 593. DOI: 10.1186/s12889-015-1879-y.
11. Glazier RH, Creatore MI, Weyman JT *et al*. Density, destinations or both? A comparison of measures of walkability in relation to transportation behaviors, obesity and diabetes in Toronto, Canada. *PLoS One* 2014; **9**: e85295. DOI: 10.1371/journal.pone.0085295.
12. Saelens BE, Handy SL. Built environment correlates of walking: a review. *Med Sci Sport Exerc* 2008; **40**: S550–S556. DOI: 10.1249/MSS.0b013e31817c67a4.Built.
13. Jeffery RW, Baxter J, McGuire M *et al*. Are fast food restaurants an environmental risk factor for obesity? *Int J Behav Nutr Phys Act* 2006; **3**: 2.
14. Morland K, Wing S, Roux AD. The contextual effect of the local food environment on residents' diets: The atherosclerosis risk in communities study. *Am J Public Health* 2002; **92**: 1761–1767. DOI: 10.2105/AJPH.92.11.1761.
15. Cummins S, Macintyre S. Food environments and obesity--neighbourhood or nation? *Int J Epidemiol* 2006; **35**: 100–104. DOI: 10.1093/ije/dyi276.
16. Fleischhacker SE, Evenson KR, Rodriguez DA *et al*. A systematic review of fast food access studies. *Obes Rev* 2011; **12**: e460–e471. DOI: 10.1111/j.1467-789X.2010.00715.x.
17. Casagrande SS, Whitt-Glover MC, Lancaster KJ, Odoms-Young AM and Gary TL. Built environment and health behaviors among African Americans: a systematic review. *Am J Prev Med* 2009; **36**(2): 174.
18. Holsten JE. Obesity and the community food environment: a systematic review. *Publ Health Nutr* 2009; **12**: 397–405.
19. Papas MA, Alberg AJ, Ewing R *et al*. The built environment and obesity. *Epidemiol Rev* 2007; **29**: 129–143.
20. Leal C, Chaix B. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. *Obes Rev* 2011; **12**: 217–230.
21. Chaix B. Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research health agenda. *Annu Rev Public* 2009; **12**: 217–230.
22. Nathan A, Pereira G, Foster S *et al*. Access to commercial destinations within the neighbourhood and walking among Australian older adults. *Int J Behav Nutr Phys Act* 2012; **9**: 133. DOI: 10.1186/1479-5868-9-133.
23. Van Cauwenberg J, De Bourdeaudhuij I, De Meester F *et al*. Relationship between the physical environment and physical activity in older adults: a systematic review. *Health Place* 2011; **17**: 458–469.
24. Mackenbach JD, Rutter H, Compernolle S *et al*. Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, The SPOTLIGHT project. *BMC Public Health* 2014; **14**: 233. DOI: 10.1186/1471-2458-14-233.
25. Alfonzo MA. To walk or not to walk? the hierarchy of walking needs. *Environ Behav* 2005; **37**: 808–836. DOI: 10.1177/0013916504274016.
26. Baranowski T, Anderson C, Carmack C. Mediating variable framework in physical activity interventions: How are we doing? How might we do better? *Am J Prev Med* 1998; **15**: 266–297.
27. Bauman AE, Sallis JF, Dzewaltowski DA *et al*. Toward a better understanding of the influences on physical activity. *Am J Prev Med* 2002; **23**: 5–14. DOI: 10.1016/S0749-3797(02)00469-5.
28. Li F, Harmer P, Cardinal BJ *et al*. Obesity and the built environment: does the density of neighborhood fast-food outlets matter? *Am J Health Promot* 2009; **23**: 203–209.
29. Beenackers MA, Kamphuis CBM, Mackenbach JP *et al*. Why some walk and others don't: exploring interactions of perceived safety and social neighborhood factors with psychosocial cognitions. *Health Educ Res* 2013; **28**: 220–233. DOI: 10.1093/her/cyt002.
30. Van Dyck D, Cerin E, Conway TL *et al*. Interacting psychosocial and environmental correlates of leisure-time physical activity: A three-country study. *Health Psychol* 2014; **33**: 699–709. DOI: 10.1037/a0033516.
31. Cerin E, Vandelanotte C, Leslie E *et al*. Recreational facilities and leisure-time physical activity: An analysis of moderators and self-efficacy as a mediator. *Health Psychol* 2008; **27**: S126–S135.
32. Van Dyck D, Deforche B, Cardon G *et al*. Neighbourhood walkability and its particular importance for adults with a preference for passive transport. *Health Place* 2009; **15**: 496–504. DOI: 10.1016/j.healthplace.2008.08.010.
33. Kaczynski AT, Robertson-Wilson J, Decloe M. Interaction of perceived neighborhood walkability and self-efficacy on physical activity. *J Phys Act Health* 2012; **9**: 208–217.
34. Rhodes RE, Brown SG, McIntyre CA. Integrating the perceived neighborhood environment and the theory of planned behavior when predicting walking in a Canadian adult sample. *Am J Health Promot* 2006; **21**: 110–118.
35. Carlson JA, Sallis SF, Conway TL *et al*. Interactions between psychosocial and built environment factors in explaining older adults' physical activity. *Prev Med (Baltim)* 2012; **54**: 68–73. DOI: 10.1016/j.ypmed.2011.10.004.
36. Lakerveld J, Brug J, Bot S *et al*. Sustainable prevention of obesity through integrated strategies: The SPOTLIGHT project's conceptual framework and design. *BMC Public Health* 2012; **12**: 793.
37. Lakerveld J, Ben-Rebah M, Mackenbach JD *et al*. Obesity-related behaviours and BMI in five urban regions across Europe: sampling design and results from the SPOTLIGHT cross-sectional survey. *BMJ Open* 2015; **5**: e008505. DOI: 10.1136/bmjopen-2015-008505.
38. Craig CL, Marshall AL, Sjostrom N *et al*. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sport Exerc* 2003; **35**: 1381–1395.
39. Bethlehem JR, Mackenbach JD, Ben-rebah M *et al*. The SPOTLIGHT virtual audit tool□: a valid and reliable tool to assess obesogenic characteristics of the built environment. *Int J Health Geogr* 2014; **13**: 1–8. DOI: 10.1186/1476-072X-13-52.
40. Lake AA, Burgoine T, Stamp E *et al*. The foodscape: classification and field validation of secondary data sources across urban/rural and socio-economic classifications in England. *Int J Behav Nutr Phys Act* 2010; **9**: 37.
41. Giskes K, van Lenthe F, Avendano-Pabon M *et al*. A systematic review of environmental factors and obesogenic dietary intakes among adults: are we getting closer to understanding obesogenic environments? *Obes Rev* 2011; **12**: e95–e106.
42. Thornton LE, Pearce JR, Kavanagh AM. Using Geographic Information Systems (GIS) to assess the role of the built environment in influencing obesity: a glossary. *Int J Behav Nutr Phys Act* 2011; **8**: 71.
43. Maroko AR, Maantay JA, Sohler NL *et al*. The complexities of measuring access to parks and physical activity sites in New York City: a quantitative and qualitative approach. *Int J Health Geogr* 2009; **8**: 34.
44. Chaix B, Merlo J, Evans D *et al*. Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Soc Sci Med* 2009; **69**(9): 1306–1310.
45. Frank L, Sallis J, Conway T *et al*. Many pathways from land use to health. *J Am Plan Assoc* 2006; **72**: 75–87. DOI: 10.1080/01944360608976725.

46. Kearney JM, McElhone S. Perceived barriers in trying to eat healthier-results of a pan-EU consumer attitudinal survey. *Br J Nutr* 1999; **81**: S133–S137.
47. Schafer JL. Multiple imputation: a primer. *Stat Methods Med Res* 1999; **8**: 3–15.
48. Rubin DB. Multiple imputation for non-response in surveys. Wiley J & Sons: New York, 1987.
49. Bodner TE. What improves with increased missing data imputations? *Struct Equ Modeling* 2008; **15**: 651–675.
50. Moons KGM, Donders RART, Stijnen T *et al*. Using the outcome for imputation of missing predictor values was preferred. *J Clin Epidemiol* 2006; **59**: 1092–1101.
51. de Mutsert R, Jager KJ, Zoccali C *et al*. The effect of joint exposures: examining the presence of interaction. *Kidney Int* 2009; **75**: 677–681.
52. Knol MJ, van der Tweel I, Grobbee DE *et al*. Estimating interaction on an additive scale between continuous determinants in a logistic regression model. *Int J Epidemiol* 2007; **36**: 1111–1118.
53. Hosmer DW, Lemeshow S. Confidence interval estimation of interaction. *Epidemiology* 1992; **3**: 452–456.
54. De Bourdeaudhuij I, Teixeira PJ, Cardon G *et al*. Environmental and psychosocial correlates of physical activity in Portuguese and Belgian adults. *Public Health Nutr* 2005; **8**: 886–895.
55. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. In: Glanz K, Rimer BK, Viswanath K (eds). Health behavior and health educaton theory, research, and practice. Jossey-Bass: San Fransisco, CA, 2008, pp. 465–486.
56. Ewing R, Cervero R. Travel and the built environment. *J Am Plan Assoc* 2010; **76**: 265–294. DOI: 10.1080/01944361003766766.
57. De Bourdeaudhuij I, Van Dyck D, Davey Rachel R *et al*. International study of perceived neighbourhood environmental attributes and Body Mass Index: IPEN Adult study in 12 countries. *Int J Behav Nutr Phys Act* 2015; **12**: 1–10. DOI: 10.1186/s12966-015-0228-y.
58. Burgoine T, Forouhi NG, Griffin SJ *et al*. Associations between exposure to takeaway food outlets, takeaway food consumption, and body weight in Cambridgeshire, UK: population based, cross sectional study. *Br Med J* 2014; **1464**: 1–10. DOI: 10.1136/bmj.g1464.
59. Hurvitz PM, Moudon AV, Aggarwal A *et al*. Proximity to food stores may not predict use. *FASEB J* **24**. URL http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L70546898.
60. Drewnowski A, Aggarwal A, Hurvitz PM *et al*. Obesity and supermarket access: proximity or price? *Am J Public Health* 2012; **102**: e74–e80.
61. Beenackers MA, Kamphuis CB, Prins RG *et al*. Urban form and psychosocial factors: do they interact for leisure-time walking? *Med Sci Sport Exerc* 2014; **46**: 293–301.
62. Beenackers MA, Kamphuis CBM, Burdorf A *et al*. Sports participation, perceived neighborhood safety, and individual cognitions: how do they interact? *Int J Behav Nutr Phys Act* 2011; **8**: 76. DOI: 10.1186/1479-5868-8-76.
63. Festinger L. A theory of cognitive dissonance. Stanford University Press: Stanford, CA, 1957.
64. Boone-Heinonen J, Gordon-Larsen P, Guilkey DK *et al*. Environment and physical activity dynamics: the role of residential self-selection. *Psychol Sport Exerc* 2011; **12**: 54–60.
65. Boone-Heinonen J, Guilkey DK, Evenson KR *et al*. Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood. *Int J Behav Nutr Phys Act* **7**: 70. DOI: 10.1186/1479-5868-7-70.
66. Charreire H, Mackenbach JD, Ouasti M *et al*. Using remote sensing to define environmental characteristics related to physical activity and dietary behaviours: a systematic review (the SPOTLIGHT project). *Health Place* 2014; **25**: 1–9. DOI: 10.1016/j.healthplace.2013.09.017.