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Built environmental correlates of cycling for transport across Europe

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ABSTRACT

This cross-sectional study aimed to determine which objective built environmental factors, identified using a virtual neighbourhood audit, were associated with cycling for transport in adults living in five urban regions across Europe. The moderating role of age, gender, socio-economic status and country on these associations was also investigated. Overall, results showed that people living in neighbourhoods with a preponderance of speed limits below 30 km/h, many bicycle lanes, with less traffic calming devices, more trees, more litter and many parked cars forming an obstacle on the road were more likely to cycle for transport than people living in areas with lower prevalence of these factors. Evidence was only found for seven out of 56 possible moderators of these associations. These results suggest that reducing speed limits for motorized vehicles and the provision of more bicycle lanes may be effective interventions to promote cycling in Europe.

1. Background

Regular physical activity (PA) can reduce the risk of chronic diseases, such as cardiovascular diseases, type 2 diabetes, and certain types of cancer (World Health Organization, 2010), and is an important part of treatment and rehabilitation of chronic conditions (World Health Organization, 2015). However, more than one third of the global adult population does not meet the PA public health recommendations of 150 min/week moderate to vigorous PA (World Health Organization, 2015, 2010). Cycling for transport has the potential to contribute to increased PA levels among adults, since it is an accessible and inexpensive form of activity that can be incorporated in everyday life throughout adult life (Menai et al., 2015; Oja et al., 2011; Pucher et al., 2010a; Rabl and de Nazelle, 2012; World Health Organization, 2010). Additionally, cycling may also lead to economic benefits, reduced CO_2-emissions, noise and air pollution, and reduced traffic congestion (Rabl and de Nazelle, 2012). Nevertheless, cycling remains an under-used form of transport compared to motorized modes in most countries (Eurobarometer, 2011). There are plentiful opportunities to increase cycling levels in European cities, given that around 40% of all trips are less than 2.5 kilometres, and 50% of all car trips are shorter than 5 kilometres (Dekoster and Schollaert, 1999; Janssens et al., 2014; Pucher and Buehler, 2007). These distances could be covered by bicycle by most adults or by most people, and cycling may often be even quicker than driving in some urban areas (Ministry of Transport/ Public Works and Water Management, 2009; Rudinger et al., 2006). Communities and cities can contribute to increasing cycling levels in adults by providing cycling-friendly environments (Buehler and Pucher, 2012; Commission of the European Communities, 2007). Next to individual-level factors (such as socio-demographics, abilities and motivations), socio-ecological models emphasise the importance of the physical or built environment in explaining behavior change (Sallis

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et al., 2006), or more specifically cycling for transport. Therefore, it is necessary to identify the most relevant physical environmental correlates of cycling for transport.

Both objective and perceived attributes of the built environment have been found to be important for cycling for transport and have previously shown distinct associations with cycling for transport (Heesch et al., 2012; Ma and Dill, 2015). Since, these two methods assess two distinct dimensions of the physical environment (Ding and Gebel, 2012; Kirtland et al., 2003; Kweon, 2006; Mackenbach et al., 2014), it is important to distinguish the objective and perceived environmental correlates of cycling for transport. Self-reported outcomes (i.e. perceived attributes of the built environment) may be biased through recall bias (i.e. participants may have difficulty to recall information) or social desirability bias (i.e. participants want to fit with social expectations) (Adams et al., 2005). Since objective measurement methods rely on information obtained by an external person or from solid data coming from a device, they often meet the disadvantages (e.g. recall bias, social desirability) of self-report methods (Sallis et al., 2009). The objective built environment is directly and indirectly (i.e. by influencing individual's perceptions of the built environment) associated with the cycling behavior (Ewing and Handy, 2009; Gebel et al., 2009; Heesch et al., 2015; Ma, 2014; Prins et al., 2009; Sallis et al., 2008, 2006; Winters et al., 2010). Most previous studies have used existing spatial data (e.g. based on Geographic Information Systems, GIS) to examine the objective built environment in relation to cycling for transport (Brownson et al., 2009; Ma and Dill, 2015). However, these studies were only able to draw conclusions about the macro-environment (i.e. raw urban planning features, such as street connectivity or residential density) because GIS-data about the micro-environment are often lacking. Nevertheless, the micro-environment is more feasible to adjust in environmental interventions since these factors are relatively small-scaled (e.g. speed limits, or vegetation) and only influenced by local actors or individuals, while adjustments to the macro-environment requires extensive collaboration between authorities (Cain et al., 2014; Swinburn et al., 1999). Consequently, evidence about the association between the objectively determined micro-environment and cycling for transport is still scarce and less consistent in comparison to the association with the macro-environment (Van Holle et al., 2014). For example, a study by Parkin et al. found that objectively measured traffic volumes were negatively related with cycling for transport (Parkin et al., 2008), while other studies have not found an association between objectively determined traffic volume and cycling for transport (Foster et al., 2011; Moudon et al., 2005). Another study has shown that the impact of traffic volume on cycling differed substantially between regions within the same country (Vandenbulcke et al., 2011). Furthermore, the role of aesthetics (e.g. presence of vegetation, trees, litter) to explain cycling for transport is inconclusive. Several studies have found positive associations between greenery and cycling for transport (Lee and Moudon, 2008; Wendel-vos et al., 2004), while other studies have not found an association between aesthetics and cycling for transport (Van Holle et al., 2012). Therefore, there is a need for empirical evidence about the association between objectively determined detailed environmental characteristics and cycling for transport.

The use of desk-based rating of the built environment using remote imaging sources such as Google Street View (GSV) or Bing Maps is now increasing (Bethlehem et al., 2014; Charreire et al., 2014; Curtis et al., 2013; Vanwolleghem et al., 2014). These remote sensing techniques can capture large-scale environments in detail efficiently, and in a way that is both standardized and quality controlled (Bethlehem et al., 2014; Charreire et al., 2014; Mooney et al., 2014; Odgers et al., 2013). Another important advantage of using a virtual audit tool is the possibility of obtaining harmonized data across different countries. Since this is a relatively new methodology, empirical evidence on the relation between objectively determined built environmental factors using virtual audits and cycling for transport is still scarce (Bauman et al., 2012; Fraser and Lock, 2010; Heinen et al., 2010; Pucher et al., 2010b; Yang and Sahlqvist, 2010).

Furthermore, previous research has already demonstrated that cycling for transport varies depending on gender, age, education level or country (Eurobarometer, 2011; Heesch et al., 2012; Rietveld and Daniel, 2004; SafetyNet, 2009; Sallis et al., 2013). Therefore, it might be necessary to include these socio-demographics as moderators in studies investigating the physical environment (Ewing and Handy, 2009; Wen et al., 2006), as these factors might help to clarify certain inconsistent associations between objective built environmental factors and cycling for transport.

This cross-sectional study aimed to identify which objective physical environmental neighbourhood factors, assessed via a virtual audit, are associated with cycling for transport in adults living in five urban regions across Europe. We also investigated whether these associations were moderated by socio-demographic variables such as age, gender, socio-economic status (SES) and urban region.

2. Methods

2.1. Study design and sampling

This study was part of the SPOTLIGHT project, a cross-European research project that aimed to enhance knowledge about the wide range of determinants of obesity, and provide an evidence-based model for effective integrated intervention approaches (Lakerveld et al., 2015, 2012). Research was conducted in five large cities (urban regions) of five European countries which were defined as study areas: Ghent region (Belgium), Paris region (France), greater Budapest (Hungary), Randstad region (The Netherlands) and Greater London (the United Kingdom). Neighbourhoods were considered according to local administrative boundaries in each country except for Hungary because their districts are much larger than the equivalent administrative areas of the other countries. Therefore, the study areas were defined as 1 km^2 areas in greater Budapest to guarantee comparability between study areas. The average study area of a neighbourhood (across all five countries) was 1.5 km^2 with a mean population density of 2700 inhabitants per neighbourhood (Lakerveld et al., 2015). The neighbourhood sampling was based on a combination of residential density and socioeconomic status (SES) data at the neighbourhood level. 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 neighbourhood type were randomly sampled (i.e. 12 neighbourhoods per country, 60 neighbourhoods in total). Subsequently, a random sample of adult inhabitants (age ≥18 years) 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 behavior, obesity-related behaviors and weight and height. A total of 6037 (10.8%, out of 55893 invited persons) 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 survey participants provided informed consent.

2.2. Measures

2.2.1. Demographic variables

The following demographic variables were reported: age, gender, educational level and country of residence (Belgium, France, Hungary, the Netherlands, or United Kingdom). Educational level of participants was divided into two categories to enable comparison between the country-specific education systems: lower education (no education, primary, lower secondary or higher secondary) and higher education (bachelor or master degree). Furthermore, age was split into two groups using the median of the study population: younger adults (18–

45 years) and older adults (46–65 years).

2.2.2. Cycling for transport

Self-reported cycling for transport was measured using an adapted form of the last seven day self-administrated long version of the International Physical Activity Questionnaire (IPAQ) (IPAQ, 2002). In this questionnaire the amount (number of days in the last seven days) and duration (average time/day) of transport-related cycling was assessed (IPAQ, 2002). The IPAQ showed good reliability (Spearman's correlation coefficients clustered around 0.80) and acceptable criterion validity (median ρ=0.30) for adults carried out in a 12-country study (Craig et al., 2003).

2.2.3. Objective physical environmental neighbourhood factors

An objective assessment of physical environmental neighbourhood characteristics was conducted using the SPOTLIGHT Virtual Audit Tool (*s*-VAT). A detailed description of the development of the S-VAT is reported elsewhere (Bethlehem et al., 2014). The S-VAT consists of 40 different physical environment items related to walking infrastructure (e.g. maintenance of sidewalks), cycling infrastructure (e.g. presence and type of bicycle lanes), public transport (e.g. presence or type of public transport), aesthetics (e.g. presence of green space), land use-mix (e.g. type of residential buildings), grocery stores (e.g. presence of supermarkets), food outlets (e.g. presence of fast-food restaurants) and recreational facilities (e.g. presence of swimming pool), and was judged in all street segments of the covered neighbourhoods. In one neighbourhood in Hungary no Google Street View (GSV) data were available at the time of the virtual audit, resulting in a total of 59 neighbourhoods in the study. In total, 4486 street segments were audited. The virtual audit was conducted by trained researchers of the SPOTLIGHT project team. A Standard Operating Procedure (SOP) was developed to assist in scoring by defining environmental characteristics and street segments, or by providing clear instructions for data extraction and storage and is available open access (Bethlehem et al., 2014). The physical environmental factors determined from the street segment level were aggregated to the neighbourhood level by accumulating the outcomes for the street segments within each neighbourhood (Feuillet et al., 2016). For example, if 100 of the 500 street segments of a neighbourhood were qualified as 'no bicycle lanes', then the feature 'no bicycle lanes present' was quantified as 0.20 in this neighbourhood. The S-VAT tool proved to have good to high criterion validity, and intra-observer and inter-observer reliability (Bethlehem et al., 2014).

In this study only environmental factors related to cycling infrastructure (eight items) and aesthetics (four out of nine items) were included. A selection of the relevant predictor variables (objective neighbourhood factors) was based on the prevalence of the items and on the variance inflation factor (VIF), ensuring no multicollinearity between these factors (VIF < 2) (Field, 2013). These selection methodologies were used by previous research (Handy and Xing, 2011; Ma and Dill, 2015; Wahlgren and Schantz, 2012; Wen et al., 2006). When collinearity occurred, the variables with the strongest correlations with the dependent variable were retained. This resulted in the eliminating of the following five environmental factors: type of street, presence of graffiti, obstacles on bicycle lanes, type of bicycle lanes, and public bicycle facilities. Finally, seven environmental factors were included in the analyses: presence of traffic calming features (such as speed humps, traffic island, roundabouts or traffic lights), speed limit ≤30 km/h, absence of bicycle lanes, cars that form an obstacle on the road, presence of green and water areas, presence of trees, presence of litter. Cars that form an obstacle on the road are defined in this study as cars parked on the road and/or partly on the sidewalk regardless of whether this is done legally or illegally. If cars are parked on the sidewalk and/or on cycle path and cyclists and/or pedestrians have to manoeuvre around these cars, they form an obstacle. For the included environmental factors, the inter-observer reliability ranged from 46.1% agreement (Cohen's kappa, k=0.010) to 99.2% agreement (k=1.00), the intra-observer reliability results ranged from 76.6% agreement (k=0.520) to 99.2% agreement (k=0.973) and the criterion validity from 60.2% agreement (k=0.168) to 98.4% agreement (k=0.947) (Bethlehem et al., 2014). The lowest percentages agreement and Cohen's kappa scores arose from the environmental factor 'litter', due to the subjectively of the judgements by the auditor, or the possible difficulty to virtually assess this item because of obstructions on the road (e.g. cars, trees) which could block the view of the images (Bethlehem et al., 2014). A detailed overview of all percentage agreement and Kappa statistics for all included SPOTLIGHT-VAT items is provided in a previous paper of the SPOTLIGHT study (Bethlehem et al., 2014).

2.3. Statistical analyses

Individuals who could not be allocated to one of the 59 selected neighbourhoods were excluded from the analyses, resulting in a sample of 5205 participants. As we were interested in the cycling behaviors of adults of working age (i.e. 18–65 years) only, the study population included 3904 adults.

Descriptive statistics of the sample were obtained using SPSS 22.0 software. To examine the main associations between objective physical environmental factors and cycling for transport, and the moderating effects of age, gender, educational level and urban region, complete case regression analyses were conducted in R (version 3.1.2) (Bolker et al., 2009) with Package 'lme4' (Douglas et al., 2016). Since the dependent variable (minutes cycling for transport per week) included an excessive number of null values (51.6%), Hurdle models were fitted for all analyses. Hurdle models consist of two parts: a logistic regression model (binomial variance and logit link function), estimating the odds of participation in cycling for transport (yes/no) and a gamma regression model (gamma variance and log link function), estimating the amount of minutes cycling for transport among those who cycled for transport in the last seven days (minutes/week). The need to model both behaviors separately has also been suggested by previous research (Ma and Dill, 2015). The models were fitted by Adaptive Gauss-Hermite Quadrature with 25 quadrature points as recommended (Bolker et al., 2009) and the Akaike's Information Criterion (AIC) minimization was used to select the most appropriate variance and link function causing the best model fit. These Hurdle models of which listwise deletion was used (complete case analysis), resulted in two regression coefficients for each predictor or independent variable: an odds ratio (OR) and a gamma regression coefficient.

For each model separately, a basic model was estimated including all main effects of the seven independent variables (objectively measured neighbourhoods factors) together with the four potential moderators (i.e. age, gender, educational level and urban regions), adjusted for neighbourhood type (i.e. neighbourhood SES and residential density) and for the clustering of participants within neighbourhoods. In a second step, each single interaction effect between a neighbourhood factor and a potential moderator was added to the basic model. Since there were seven neighbourhood factors and four potential moderators, 28 possible models were fitted for each part of the Hurdle model. The interaction effects that were found to be significant ($p < 0.05$) in the previous step were then added to the basic model. Finally, in order to simplify this final model, non-significant interaction effects were removed from the model. To calculate the estimates for each category, stratified analyses were performed. These steps were followed for each part of the Hurdle models, namely the logistic regression model and the gamma regression model. Level of significance was set at a two-sided α of 0.05.

Table 1
Descriptive characteristics of the participants (n=3,904).

Characteristics	
Age in years (M (SD)) (n=3,904)	45.5 (12.3)
Women (%) (n=3,887)	58.0
Urban regions (country) (%) (n=3,904)	
-Ghent region (Belgium)	31.9
- Paris region (France)	14.4
- Greater Budapest (Hungary)	15.0
- Randstad region (Netherlands)	28.2
- Greater London (UK)	10.5
Level of education (%) (n=3,552)	
- Lower	42.1
- Higher	57.9
Type of neighbourhood (%) (n=3,904)	
- H-SES/H-dens	26.9
- H-SES/L-dens	22.1
- L-SES/H-dens	26.5
- L-SES/L-dens	24.5
Current cycling for transport level (n=3,730)	
- Cycling for transport in the last week (%)	48.4
- Min/week among those who cycled (M (SD))	139.4 (237.9)
***Objective built environmental neighbourhood factors* (n=3,904)**[a]	
- Traffic calming features (M (SD))	0.36 (0.24)
- Speed limit ≤ 30 km/h (M (SD))	0.45 (0.32)
- No bicycle lanes (M (SD))	0.83 (0.14)
- Cars form obstacle on the road (M (SD))	0.30 (0.23)
- Presence of green and water areas (M (SD))	0.37 (0.34)
- Presence of trees (M (SD))	0.82 (0.23)
- Presence of litter (M (SD))	0.19 (0.25)

M= mean; SD= standard deviation; H-SES= high socio-economic status; L-SES= low socio-economic status; H-dens= high residential density; L-dens= low residential density
[a] = percentages of street segments in the neighbourhoods in which these characteristics are present

3. Results

3.1. Descriptive statistics

The characteristics of the study population and the presence of objectively measured physical environmental neighbourhood factors are presented in Table 1.

3.2. Main and moderated associations for the odds of cycling for transport

Table 2 shows the results of the logistic regression model adjusted for age, gender, education level, neighbourhood type, urban region and for the clustering of participants within neighbourhood. Living in a neighbourhood with more traffic calming features, or fewer bicycle lanes, was associated with being less likely to engage in cycling for transport in the last seven days. On the other hand, living in a neighbourhood with more streets where the speed limit is ≤30 km/h, more parked cars that form an obstacle on the road, more trees, or more litter were all associated with being more likely to engage in cycling for transport.

The significant moderating effects found for this model are presented in Table 3. The association of presence of traffic calming features with engaging in cycling for transport was significantly moderated by urban region ($p < 0.001$), and turned out to be only significant for the Ghent region in Belgium ($p < 0.05$). Residents from the Ghent region living in a neighbourhood with more traffic calming features were more likely to engage in cycling for transport than those living in a neighbourhood with fewer traffic calming features

Table 2
Main associations for the odds of cycling for transport (Logistic model) and for minutes cycling for transport (Gamma model).

Main effects	**Logistic model**[b] (n=3514; AIC=3999.9) *OR (95% CI)*	**Gamma model**[c] (n=1713; AIC=1641.6) *Exp β*[d] *(95% CI)*
Traffic calming features	0.02 (0.00, 0.31)[**,a]	0.90 (0.63, 1.28)
Speed limit ≤30 km/h	6.68 (1.57, 28.39)[*]	1.13 (0.79, 1.62)
No bicycle lanes	0.09 (0.01, 0.68)[*]	0.80 (0.46, 1.38)
Cars form an obstacle on the road	14.56 (4.26, 49.80)[***,a]	1.61 (1.04, 2.51)[*,a]
Green and water areas	0.67 (0.24, 1.87)[a]	1.08 (0.88, 1.33)
Trees	15.65 (3.58, 68.37)[***,a]	0.68 (0.49, 0.93)[*]
Litter	37.37 (2.91, 479 0.59)[**,a]	0.99 (0.71, 1.39)[a]

OR= odds ratio of engaging in cycling for transport; CI= confidence interval;
[a] = variable which is significantly moderated;
[b] The logistic model estimates the association between the independent variables (physical environmental factors) and the odds of engaging in cycling for transport;
[c] The gamma model estimates the association between the independent variables (physical environmental factors) and the amount of minutes cycling for transport among those who cycled for transport in the last seven days;
[d] Exp β= exponent of β, all gamma models were fitted using a log link function, the exponent of β can be interpreted as the proportional increase of the dependent variable with one percentage increase in the independent variable; AIC= Akaike's Information Criterion
[*] $p < 0.05$,
[**] $p < 0.01$,
[***] $p < 0.001$

(OR=16.00, 95% CI=1.16, 220.82). However in the Paris region, greater Budapest, the Randstad region and Greater London no significant association was found between the presence of traffic calming features and the odds of cycling for transport. Another significant moderating effect by urban region was found for the association between presence of litter and the odds of engaging in cycling for transport: the effect of litter was only significant in the Paris Region and not in the Ghent region, greater Budapest, the Randstad region, and Greater London. Residents of the Paris region living in a neighbourhood with more litter were less likely to engage in cycling for transport than residents of the Paris region living in a neighbourhood with less litter (OR=0.04, 95% CI=0.00, 0.06).

Age moderated the association between cars that form an obstacle on the road and the odds of engaging in cycling for transport ($p < 0.001$). This effect was significant for both younger adults (18–45 years) and older adults (46–65 years) from this sample but was stronger in the younger population. Younger adults living in a neighbourhood with more cars that form an obstacle on the road were more likely to engage in cycling for transport (OR=14.03, 95% CI=4.30, 45.76) in comparison to older adults (OR=6.45, 95% CI=1.64, 25.32).

The association of presence of trees with engaging in cycling for transport was significantly moderated by education ($p < 0.001$), and turned out to be only significant for people with a low education level and not significant for people with a high education level. People with a low education level living in a neighbourhood with more trees were more likely to engage in cycling for transport (OR=15.93, 95% CI=3.57, 71.11).

Lastly, the association of presence of green and water areas with engaging in cycling for transport was significantly moderated by gender ($p < 0.05$). However, this effect was not significant for either men or women.

3.3. Main and moderated associations for minutes of cycling for transport

The results of the gamma model are shown in Table 2. Living in a neighbourhood with more cars that form an obstacle on the road was associated with more minutes of cycling for transport per week (exp(β) =1.61, 95% CI=1.04, 2.51). Living in a neighbourhood with more trees

Table 3
Moderating associations for the odds of cycling for transport (Logistic model) and for minutes cycling for transport (Gamma model).

	Logistic model[a] (n=3,514 ; AIC=3999.9)	**Gamma model**[b] (n=1,713 ; AIC=1641.6)
Moderating effects	*OR (95% CI)*	*Exp β*[c] *(95% CI)*
Traffic calming features x regions***	***2.19 (1.40, 3.41)******	
- Ghent region (Belgium)	16.00 (1.16, 220.82)*	
- Paris region (France)	0.59 (0.05, 6.87)	
- Greater Budapest (Hungary)	0.00 (0.00, 1.08 e12)	
- Randstad region (Netherlands)	1.65 (0.30, 9.24)	
- Greater London (UK)	5.17 (0.01, 4792.44)	
Cars form an obstacle on the road x age***	***0.23 (0.10, 0.51)******	
- Younger adults (18–46 years)	14.03 (4.30, 45.76)***	
- Older adults (46–65 years)	6.45 (1.64, 25.32)**	
Green and water areas x gender*	***0.42 (0.20, 0.85)****	
- Men	0.96 (0.40, 2.30)	
- Women	1.11 (0.32, 3.81)	
Trees x education**	***0.19 (0.07, 0.52)*****	
- Low educational level	15.92 (3.57, 71.11)***	
- High educational level	3.76 (0.91, 14.52)	
Litter x regions***	***15.15 (4.59, 50.07)******	
- Ghent region (Belgium)	0.04 (0.00, 1.53)	
- Paris region (France)	0.04 (0.00, 0.07)*	
- Greater Budapest (Hungary)	0.00 (0.00, 7.31 e9)	
- Randstad region (Netherlands)	0.17 (0.03, 1.15)	
- Greater London (UK)	3.40 (0.13, 80.62)	
Cars form an obstacle on the road x regions**		***1.59 (1.14, 2.22)*****
- Ghent region (Belgium)		2.25 (0.55, 9.20)
- Paris region (France)		7.19 (0.00, 5.64 e9)
- Greater Budapest (Hungary)		78.77 (0.24, 26347.81)
- Randstad region (Netherlands)		0.82 (0.41, 1.65)
- Greater London (UK)		0.97 (0.01, 90.27)
Litter x gender*		***0.78 (0.64, 0.96)****
- Men		1.07 (0.74, 1.56)
- Women		1.38 (0.92, 2.07)

OR=odds ratio of engaging in cycling for transport; CI= confidence interval;
[a] The logistic model estimates the association between the independent variables (physical environmental factors) and the odds of engaging in cycling for transport;
[b] The gamma model estimates the association between the independent variables (physical environmental factors) and the amount of minutes cycling for transport among those who cycled for transport in the last seven days;
[c] Exp β= exponent of β, all gamma models were fitted using a log link function, the exponent of β can be interpreted as the proportional increase of the dependent variable with one percentage in the independent variable; AIC= Akaike's Information Criterion
* $p < 0.05$,
** $p < 0.01$,
*** $p < 0.001$;

was associated with fewer minutes of cycling for transport per week (exp(β)=0.68, 95% CI=0.49, 0.93).

The significant moderating effects found for the gamma model are presented in Table 3 as well. The association of cars that form an obstacle on the road with the amount of cycling for transport was significantly moderated by urban region ($p < 0.01$). In stratified analyses, the association was non-significant in all urban regions included. Finally, the association between the presence of litter with the amount of cycling for transport among those who indicated to have cycled in the last seven days was significantly moderated by gender ($p < 0.05$). However, this association appeared not to be significant in the analyses stratified by gender.

4. Discussion

We investigated the association between objectively measured built environment characteristics and cycling for transport in and across five urban regions across Europe among adults. Furthermore, we explored the moderating role of age, gender, education and urban region on these associations.

Overall, results showed that living in neighbourhoods with more streets where speed limits are ≤30 km/h, with more bicycle lanes, with traffic calming devices being absent, more trees present, more litter present and with more parked cars that form an obstacle on the road was associated with being more likely to engage in cycling for transport. Previous studies have indicated that cyclists find it important to have restrictive speeds for motorized traffic when they have to share the road (Mertens et al., 2016b, 2015; Pucher and Buehler, 2008, 2007; Titze et al., 2010). Moreover, zones where the maximum speed is limited to 30 km/h are proved to reduce the number and severity of bicycle crashes (Grundy et al., 2009). In addition to speed limits of < 30 km/h, the presence of bicycle lanes in the neighbourhood was also associated with higher odds of cycling for transport. This finding supports results from previous studies (Fraser and Lock, 2010; Ma and Dill, 2015; Mertens et al., 2016b; Winters et al., 2010).

The presence of parked cars that form an obstacle on the road was associated with higher odds of engaging in cycling for transport and also with more minutes cycling for transport per week. However, previous qualitative research demonstrated that cyclists experience these obstacles as disturbing, since they do not allow a good overview of the traffic situation and could be dangerous because of the possibility of suddenly opening doors (Ghekiere et al., 2014). A possible explanation for this finding might be the fact that the cycling levels are higher in busy urban neighbourhoods with high levels of car use as well as bicycle use (Douglas et al., 2011; Van Holle et al., 2012). Consequently, people will cycle in such neighbourhoods despite of the parked cars even if they bother them. Additionally, the association was significantly moderated by age: the association was stronger for the younger adults (18–45 years) compared to the older adults (46–65 years) and could be possibly explained by the fact that younger adults are more likely to feel safe to cycle in these traffic dense neighbourhoods, and are thus more likely to cycle in them.

The environmental factors mentioned above appeared to be rather general predictors, with the same direction of associations across age groups, gender, educational level, or urban region (with the exception of a few associations). If supported by evidence from (quasi-) experimental or longitudinal studies this is promising for future interventions, as focusing on these specific factors would not disadvantage specific subgroups. For example, if these results are duplicated by other studies that allow more for causal inference, adapting speed limits to ≤30 km/h and providing clear and unobstructed cycling lanes might help to encourage more population groups to cycle for transport.

However, for some other environmental factors, moderating effects of socio-demographic variables were found. People living in a neighbourhood with more trees were more likely to engage in cycling for transport, but this was only significant for individuals with a low educational level, while in general the presence of trees was associated with fewer minutes cycling for transport per week among those who had cycled in the last seven days. Furthermore, the main effect of providing traffic calming features and the presence of litter showed respectively a positive and negative association with cycling for transport. However, a significantly moderated effect by urban region was found; providing traffic calming features may increase the likelihood of cycling for transport in the Ghent region and removing litter may help in the Paris region. No association with the other regions was detected. A possible explanation of the moderated effect is that the associations of the other countries are in the opposite direction, but not strong enough to be significant. Examining a larger sample in each subgroup (e.g. educational level) or each urban region might give more clarity about association in these smaller subgroups. These findings need further exploration and future studies should replicate these findings to confirm the importance of specific built environmental features for some subgroups.

A previous study indicated that the objective physical environment had the greatest influence on the decision about whether or not to cycle and not on the amount or duration of cycling (Ma and Dill, 2015). Consequently, it might be that environmental factors in the residential neighbourhood are less important when individuals cycle longer distances, since they are likely to travel through and to other neighbourhoods. Therefore, future studies examining the built environmental determinants of the amount of cycling will also need to look at the physical environmental factors of the neighbourhoods adjacent to the one a person lives in. Another possibility is to assess also the work environment of individuals in addition to their residential environment (Chaix et al., 2012; Kestens et al., 2010; Perchoux et al., 2013). Since the cycling environment of an individual is often larger than the determined residential neighbourhood, it needs to be investigated further which neighbourhood definition is most relevant to map the activity space regarding cycling for transport of an individual.

In a previously conducted study (Mertens et al., 2016a) within the SPOTLIGHT project, we investigated the perceived environment related to cycling. Although most of the perceived measures were not comparable to the objective measures, we did find that perceived lower traffic speeds were associated with higher odds of cycling for transport. These results are comparable with findings in this study, showing that objectively assessed traffic speed levels of 30 km/h or less were associated with higher odds of cycling. However, people's perceptions of their environment may not always match with objective characteristics of the environment in which they live (Gebel et al., 2011; Ma and Dill, 2015; Roda et al., 2016). For example, in the current study the objectively measured attribute 'no bicycle lanes' was positively associated with the odds of engaging in cycling, however, the perceived attribute 'presence of bicycle lanes' previously showed no association with cycling for transport (Mertens et al., 2016a). Nevertheless, both objective and perceived attributes of the built environment have been found to be important for cycling for transport and future research is needed to provide more insight about this association.

Strengths of this study include a large study sample of European adults living in five urban regions was used, enabling the possibility to perform inter-country comparisons. Additionally, the use of the validated GSV tool which can capture the objective physical environment in detail (Bethlehem et al., 2014; Curtis et al., 2013; Rundle et al., 2011). However, the use of GSV images also has some disadvantages, such as the risk of some obstructed views (e.g. obstacles on the images) or the impossibility to report field audit items such as noises, odours, traffic speeds and cycle path widths (Rundle et al., 2011). In addition, there were some locations where there was a mismatch in the dates of the GSV data, with the oldest images dated from 2008, and the field audits conducted in 2014 (Bethlehem et al., 2014). Furthermore some other limitations should be acknowledged. First, the cross-sectional study design does not support causal inferences, and does not exclude the problem of self-selection (e.g. Do people cycle more because they live in a cycling-friendly environment, or do they choose to live in a cycling-friendly environment because they like to cycle?) (Transportation Research Board, 2005). Therefore, stronger experimental or longitudinal designs are needed to close this research gap (Bauman et al., 2012; Sallis et al., 2013). Furthermore, our present findings need to be confirmed by studies with those stronger designs since they enable causal interference with regard to the impact of the objective physical environmental factors on cycling for transport (Bauman et al., 2012; Ferdinand et al., 2012). Second, several moderating effects turned out not to be significant when looking only at the subgroups. Consequently, examining a larger sample might give more clarity about associations in these smaller subgroups. Third, some pronounced high or low odds ratios are possible due to a small variance in built environmental factors or in the behavior between the five urban regions. Fourth, the results including the objective environmental factor 'litter' should be interpreted with some caution, since this factor has the lowest percentages agreement and Cohen's kappa scores (Bethlehem et al., 2014). Fifth, the low response rate of (10%), while common in large European surveys (Neill et al., 1995), means that generalization of these results should be approached with caution. Furthermore, since most participants come from Belgium and the Netherlands, we have to be careful when applying those general results to each country separately. Lastly, we have to be aware of the modifiable Areal Unit Problem (MAUP) which is a result of the definition of data collection units. In the SPOTLIGHT project, neighbourhoods were defined according to local administrative boundaries, but results (objective physical environment – cycling for transport) could be entirely different if the 'neighbourhood' was defined differently (i.e. MAUP). We suggested that future studies examining the built environmental determinants of the amount of cycling should also look at the physical environmental factors of the adjacent neighbourhoods in which one lives or other neighbourhoods (e.g. work environment of individuals) as cyclists often travel longer distances than only their residential neighbourhood. Since the cycling environment of an individual is often larger than the determined residential neighbourhood, it needs to be investigated further which neighbourhood definition is most relevant to map the activity space regarding cycling for transport of an individual. Taking into consideration the MAUP, it would be even better to objectively determine the activity space of an individual, for example with the use of GPS devices. These devices make it possible to investigate which cycling routes participants' actual take (e.g. the shortest route, the safest route or the prettiest route) and to compare the objective environmental factors along these routes.

5. Conclusions

People living in neighbourhoods with a preponderance of speed limits below 30 km/h, many bicycle lanes, with traffic calming devices being absent, more trees present, more litter present and many parked cars forming an obstacle on the road were more likely to cycle for transport than people living in areas with lower prevalence of these factors. Among people who reported cycling in the previous seven days, those living in neighbourhoods with more parked cars (as road obstacles), and neighbourhoods with fewer trees, reported more time per week spent cycling for transport. Moderating effects were only found for seven out of 56 examined possible moderators. If supported by evidence from large-scale (quasi-) experimental or longitudinal studies this is promising for future interventions, as focusing on these specific factors could be positive for everyone, or could be more favourable for some subgroups in comparison to others, without disadvantaging those others. Consequently, our study results suggest the need to test in future studies that the provision of bicycle lanes and reducing speed limits for motorized vehicles may be effective interventions to promote cycling in Europe. Future studies examining the built environmental determinants of the amount of cycling should also look at the physical environmental factors of the adjacent neighbourhoods in which one interacts and of the work environments.

Authors' contributions

The WP3 SPOTLIGHT group (SC, JL, JM, HB, HR, KG and JMO) developed the questionnaire, research protocol and conducted the data collection. LM performed the data analysis and drafted the manuscript supervised by SC, FG, BD, IDB. All other co-authors critically reviewed and revised versions of the manuscript and each of them read and approved the final manuscript.

Conflict of interest

The authors declare that they have no competing interests.

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