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Supplement Article

Perceived environmental correlates of cycling for transport among adults in five regions of Europe

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Summary

Regular cycling for transport is an important potential contributor to daily physical activity among adults. Characteristics of the physical environment are likely to influence cycling for transport. The current study investigated associations between perceived physical environmental neighbourhood factors and adults' cycling for transport across five urban regions across Europe, and whether such associations were moderated by age, gender, education and urban region. A total of 4,612 adults from five European regions provided information about their transport-related cycling and their neighbourhood physical environmental perceptions in an online survey. Hurdle models adjusted for the clustering within neighbourhoods were performed to estimate associations between perceived physical environmental neighbourhood factors and odds of engaging in cycling for transport and minutes of cycling for transport per week. Inhabitants of neighbourhoods that were perceived to be polluted, having better street connectivity, having lower traffic speed levels and being less pleasant to walk or cycle in had higher levels of cycling for transport. Moderation analyses revealed only one interaction effect by gender. This study indicates that cycling for transport is associated with a number of perceived physical environmental neighbourhood factors across five urban regions across Europe. Our results indicated that the majority of the outcomes identified were valid for all subgroups of age, gender, education and across regions in the countries included in the study.

Keywords: Built environment, cycling, physical activity, SPOTLIGHT.

Abbreviations: SES, socioeconomic status.

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Background

Despite the established health benefits of physical activity (1), a high proportion of European adults do not achieve the public health recommendations for physical activity (2,3). Active transport (e.g. cycling to work and shops or friends) can make a major contribution to daily physical activity (4). Cross-sectional studies indicate that cycling for transport is associated with lower body weight, improved cardiovascular health and lower morbidity in adults (4–7). Besides these health benefits, cycling has many other positive effects such as economic, social and environmental and traffic management advantages (8–17). Physical environments that support cycling can help to increase cycling for transport (18,19). The physical environment can be seen as the wider built environment (20) and is defined as 'objective and perceived characteristics of the physical context in which people spend their time (e.g., home and neighbourhood), including aspects of urban design, traffic density and speed, distance to and design of venues for physical activity (e.g., parks), crime and safety' (21). However, associations between the physical environment and cycling for transport have been less thoroughly investigated than associations with walking, leisure-time physical activity or total physical activity (22,23). Furthermore, a recent study by Kerr *et al.* (2015) emphasizes the importance of investigating perceived environmental neighbourhood factors independently for walking and for cycling for transport, as highly walkable environments may not support cycling for transport (24). In addition, results that are available on cycling for transport are much more inconsistent (22,25–28).

The physical environment can be measured in two main ways: self-reported or objective. These methods assess two distinct dimensions of the physical environment (29–32). For example, a study showed that individuals whose perceptions of the walkability of their neighbourhood were lower than was indicated by objective measures were more likely to decrease their walking for transport than individuals who had a more accurate perception of the walkability of their neighbourhood (33). Furthermore, a recent review found that the consistency of associations between the physical environment and physical activity is strongly influenced by the modes of measurements (objective vs. perceived) (34). Therefore, it is important to distinguish objective and perceived environmental correlates (32) and choose the appropriate data depending on what purpose you want to achieve or which behaviour you want to assess (31). Because neighbourhood perceptions may be more closely related to actual behaviours (35,36), insight into the perceived physical environmental neighbourhood factors associated with cycling behaviour is important.

Demographic factors can influence neighbourhood perceptions as well as cycling behaviour (29). For example, it may be that people from different educational or cultural backgrounds view the same environment differently, leading to different neighbourhood perceptions. However, little is known about whether the association between perceived physical environmental neighbourhood factors and cycling differs between different population subgroups. Previous studies suggest that men, younger adults and highly educated people are more likely to engage in cycling for transport (37–39), and that socio-cultural factors may influence cycling behaviour (40) due to differences in cycling culture across countries (41). Nevertheless, it is unknown if the strength of association between physical neighbourhood environmental characteristics and cycling for transport is moderated by these demographic factors.

Therefore, the current cross-sectional study aimed to determine which perceived physical environmental neighbourhood factors are associated with adults' cycling for transport in five urban regions across Europe. Additionally, the moderating role of demographic variables such as age, gender, SES and country on these associations was investigated.

Methods

Study design and sampling

This study was part of the SPOTLIGHT project (42,43), conducted in five urban regions across Europe: Ghent region (Belgium), Randstad region (the Netherlands), Budapest (Hungary), Paris region (France) and Greater London (UK). Sampling of neighbourhoods and recruitment of participants have been described in detail elsewhere (42). Briefly, neighbourhood sampling was based on a combination of residential density and 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, per neighbourhood, a random sample of adult inhabitants was invited to participate in an online survey. A total of 6,037 out of 55,893 invited individuals (10.8% response rate) participated in the study between February and September 2014. Only participants aged between 18 and 65 years were included for the present study, because cycling is considerably less prevalent among elderly people (41), resulting in a final sample of 4,579 adults.

Participants answered questions on demographics, neighbourhood perceptions, social environmental factors, health, motivations and barriers for healthy behaviour, obesity-related behaviours and weight and height. The study was approved by the corresponding local ethics committees of participating countries, and all participants in the survey provided informed consent.

Measures

Demographic variables

Self-reported demographic variables included age, gender, country of residence (Belgium, France, Hungary, the Netherlands or UK) and educational level. Higher education was defined as a tertiary education degree (bachelor or master degree); lower education was defined as below a tertiary education (no education, primary, lower secondary or higher secondary).

Cycling for transport

Cycling for transport was measured using the International Physical Activity Questionnaire (long, last seven days self-administrated version) by asking the frequency (number of days in the last seven days) and duration (average time per day) of transport-related cycling (44). Self-reported physical activity assessed by International Physical Activity Questionnaire showed good reliability (Spearman's correlation coefficients clustered around 0.80) and acceptable criterion validity (median $\rho = 0.30$) for adults in a 12-country study (45).

Perceived physical environmental neighbourhood factors

Perceived physical environmental neighbourhood factors were assessed based on the environmental perceptions items from the validated Assessing Levels of Physical Activity environmental questionnaire (46,47) and some additional items. This questionnaire, partly based on the Neighbourhood Environment Walkability Scale questionnaire, was developed from the need to use a standard questionnaire in Europe in which the focus was broader than just walkability (46). The main problem with the globally used Neighbourhood Environment Walkability Scale questionnaire is that characteristics of the European physical environment (e.g. housing density and land use mix) differ markedly from those in the USA or Australia, affecting its suitability in the European context (47). Respondents were asked to what extend they agreed with the following statements (i) there are special lanes, routes or paths for cycling in my neighbourhood; (ii) there is heavy traffic in my neighbourhood related to cycling; (iii) the cycle paths in my neighbourhood are well maintained; (iv) my neighbourhood is a pleasant area for walking or cycling; (v) my neighbourhood is generally free from litter, waste or graffiti; (vi) the air in my neighbourhood is polluted; (vii) the speed of traffic in my neighbourhood is usually low; (viii) the level of crime in my neighbourhood is high and (ix) I have a choice of different routes for walking or cycling in my neighbourhood. All environmental perceptions were rated on a five-point Likert scale ranging from 1 (totally disagree) to 5 (totally agree). For the statistical analyses, items were recoded so that higher scores represented what were hypothesized to be more positive values for a bicycle-friendly environment.

Statistical analyses

Descriptive statistics of sample characteristics were performed using SPSS 22.0 software, and one-way analysis of variance was used to detect differences in cycling levels between different urban regions across Europe. Hurdle models, adjusting for the clustering of participants within neighbourhoods, were performed using the lme4-packages in R version 3.1.2 (48). Hurdle models were used because the dependent variable (minutes cycling for transport per week) was positively skewed and contained a considerable number of null values (56.3% of the participants did not cycle for transport); hereby, violating the assumption of normality and implying that general linear regression analyses could not be performed. Correlations between predictor variables were checked with the variance inflation factor. All values were lower or equal to 1.45, indicating no multicollinearity (49). The first part of hurdle models consisted of analysing associations between the independent variables (i.e. the nine perceived physical environmental neighbourhood factors) and *the odds of participation in cycling for transport among adults* (yes/no cycling for transport in last 7 days) using a logistic regression model: binomial variance and logit link function. The second part of hurdle models consisted of assessing associations between the independent variables and the *amount (*minutes per week*) of cycling for transport among adults who cycled for transport in the last 7 days* (i.e. gamma variance and log link function, selected based on Akaike's information criterion) (48). Hence, the hurdle models resulted in two regression coefficients for each independent variable: an odds ratio (OR) and a gamma regression coefficient. The models were fitted by adaptive Gauss–Hermite quadrature with 25 quadrature points as recommended (48). A hurdle model was chosen over the traditional Tobit model because a hurdle model overpowers the restrictive theory to use the same equation for both outcomes. Hurdle models create two separate equations; in this case, one equation is for whether people cycle for transport and the other is to determine how much time people spent cycling for transport (50,51). In contrast, Tobit models do not make any distinction between the two stages of decision-making (50), making this method less suitable in health applications.

First, a basic model including all main effects of the nine independent variables and four potential moderators (i.e. age, gender, education level and urban regions) were estimated. Second, single interaction models were estimated in which all interaction effects between the perceived physical environmental neighbourhood factors, and the potential moderators were entered separately into the basic model. Third, all single interaction effects from the second step surpassing the statistical threshold of $p < 0.05$ were added simultaneously to the basic model. Non-significant interaction effects were not entered in the final model. Both models are presented in tables, while significant interaction effects observed in the final models are described in the text. Significant interaction terms were probed according to established procedures (52). All analyses were adjusted for type of neighbourhood (i.e. neighbourhood SES and residential density). Level of significance was set at a two-sided α of 0.05.

Results

Descriptive statistics

In total, data from 4,579 adults, aged between 18 and 65 years, were available for the present analyses. More than half of the sample were women (58.5%) and highly educated (57.3%). Furthermore, almost half (43.5%) of the sample cycled for transport in the last 7 days. Other descriptive characteristics of the sample and the descriptive data on neighbourhood perceptions are shown in Table 1. Table 2 shows the significant differences in cycling data in the five different urban regions (overall effect: $F = 125.3$; $p < 0.001$). Participants cycled most for transport in the Randstad region (the Netherlands) and the Ghent region (Belgium), followed by greater Budapest (Hungary), the Paris region (France) and Greater London (UK), where the cycling levels did not differ significantly from those of greater Budapest or the Paris region.

Main and moderated associations for the odds of cycling for transport

From the logistic model (Table 3), low perceived traffic speed, high perceived choice between different routes to walk/cycle and high perceived air pollution in the neighbourhood were positively associated with the odds of engaging in cycling for transport. A one-unit increase of 'low traffic speed' (i.e. a lower perception of traffic speed) in the neighbourhood was associated with 10% higher odds of having cycled for transport in the last 7 days. Furthermore, a one-unit increase in perception of amount of choices between different routes to walk or cycle was associated with 38% higher odds of having cycled in the last 7 days. Lastly, a one-unit increase of 'no air pollution' (i.e. lower self-reported air pollution) was associated with 19% lower odds of having cycled in the last 7 days.

The association of perceived air pollution with engaging in cycling for transport was significantly moderated by gender ($p = 0.007$). Men reporting (higher levels of 'no air pollution') less air pollution in their neighbourhood were less likely to have cycled in the last 7 days (OR = 0.84; 95% CI = 0.75, 0.95), while there was no significant association observed among women (OR = 0.93; 95% CI = 0.84, 1.04). No other moderation effects were found to be significant.

Main and moderated associations for minutes of cycling for transport

In the gamma model (Table 3), perceived pleasantness of the environment in relation to walking or cycling as well as perceived less air pollution were negatively associated with minutes per week cycling for transport among those who indicated to have cycled in the last seven days. A one-unit higher perceived pleasant environment to walk or cycle was associated with 10% fewer minutes of cycling for transport per week. Participants who agreed more strongly with the statement that their neighbourhood had low levels of air pollution cycled less for transport in the last week. In other words, a one-unit increase of 'no air pollution' (i.e. lower self-reported air pollution) was associated with 6% less time (minutes) of cycling for transport per week among those who cycled for transport. No moderation effects were found to be significant.

Discussion

In total, five significant associations (out of the 18 associations tested) between the physical environment and cycling for transport by adults were found. Low perceived traffic speed, higher perceived amount of choices between different routes to walk or cycle and higher perceived air pollution were positively associated with the odds of engaging in cycling for transport. Furthermore, a less pleasant environment to walk or cycle and higher perceived air pollution were associated with more minutes of cycling for transport in the last week. For only one of these associations (air pollution and the odds of engaging in cycling for transport), some evidence for moderation by gender was found. The small number of associations between the physical environment and cycling for transport were not as expected since previous studies using manipulated photographs (53,54) found significant associations between several physical environmental factors (e.g. presence of cycle paths, good maintained cycle paths and even cycle paths) and the street's appeal to cycle for transport. A possible explanation for these different outcomes is the fact that the previous research did not investigate actual cycling behaviour but focused on small-scaled street-setting features (i.e. micro-environmental factors). In the present study, both micro-

Table 1 Descriptive characteristics of the participants (*n* = 4,579)

Characteristics	
Age in years (M ± SD) (*n* = 4,517)	45.2 ± 12.4
Women (%) (*n* = 4,538)	58.6
Urban regions (country) (%) (*n* = 4,579)	
- Ghent region (Belgium)	30.0
- Paris region (France)	15.0
- Greater Budapest (Hungary)	16.2
- Randstad region (Netherlands)	24.9
- Greater London (UK)	14.0
Level of education (%) (*n* = 4,146)	
- Lower	43.0
- Higher	57.0
Type of neighbourhood (%) (*n* = 4,505)	
- H-SES/H-dens	25.1
- H-SES/L-dens	25.4
- L-SES/H-dens	22.2
- L-SES/L-dens	27.3
Current cycling for transport level (*n* = 4,579)	
- Cycling for transport in the last week (%)	43.7
- Min/week among those who cycled (M ± SD)	288.3 ± 272.4
Perceived physical environmental neighbourhood factors	
- Presence of cycle paths (M ± SD) (*n* = 4,215)	3.6 ± 1.3
- Good maintained cycle paths (M ± SD) (*n* = 3,932)	3.3 ± 1.2
- Pleasant environment to walk/cycle (M ± SD) (*n* = 4,320)	3.8 ± 1.1
- Free from litter, graffiti and trash (M ± SD) (*n* = 4,330)	3.2 ± 1.3
- Low traffic speed (M ± SD) (*n* = 4,297)	2.8 ± 1.2
- Choice between different routes to walk/cycle (M ± SD) (*n* = 4,275)	3.9 ± 1.0
- No busy traffic (M ± SD) (*n* = 4,312)	2.4 ± 1.2
- No air pollution (M ± SD) (*n* = 4,265)	3.0 ± 1.2
- Low level of crime (M ± SD) (*n* = 4,270)	3.4 ± 1.1

H-dens = high residential density; H-SES = high socioeconomic status; L-dens = low residential density; L-SES = low socioeconomic status; M = mean; SD = standard deviation.

environmental and macro-environmental factors were included. Macro-environmental factors are regarded as 'raw' urban planning features (e.g. connectivity of the street network, residential density and land use mix diversity), which are more complex to modify compared with the reconfiguration of micro-environmental factors (55). From our study, it might be concluded that macro-environmental factors (e.g. air pollution and choice between different routes to walk/cycle), despite their difficult changeability, appear to be more important than the micro-environmental factors.

First, low perceived traffic speed was positively associated with the odds of engaging in cycling for transport. In the literature, there is overall consensus that safety of cyclists can be increased by reducing the speed of motorized traffic on secondary roads (56). In the Netherlands, Denmark and Germany, the overall bicycle network was greatly enhanced by traffic-calming interventions in cities, reducing the speed limit to 30 km/h in most residential streets (57). Research has indicated that safer and less stressful cycling routes are preferable to streets with fast-moving traffic for children, older people and women; (56) our findings did not indicate moderation by gender or age, although we only considered the age range of 18 to 65 years in this analysis.

Second, higher perceived air pollution was associated with higher odds of engaging in cycling for transport and more minutes of cycling for transport in the last week. This finding may be explained by the fact that cyclists are more exposed to, and therefore may be more aware of air pollution (i.e. reverse causality). The same counter-intuitive result was found in a recent cross-sectional study by Feuillet *et al.*, (58) in which air pollution was positively associated with active transport. It may also be that there are additional benefits to using a bicycle in neighbourhoods with high levels of air pollution, as a result of greater traffic density e.g. using your bike in such a car-traffic dense neighbourhood may save time. This association was only significant among men. It may be that cycling for transport is more influenced by the instrumental component (e.g. because it is efficient) in men than women, while for women, the emotional and safety component remains more important (e.g. cycling for transport has to be fun and enjoyable as well) (37,59,60).

Furthermore, our results indicated that higher perceived street connectivity (i.e. choice between different routes to walk or cycle) was positively related with the odds of engaging in cycling for transport, but not with minutes of cycling for transport in the last week. Previous research has also identified an association between perceived street connectivity and cycling for transport (26,61–63). The same contrasting result for the association between cycling for transport and perceived street connectivity (i.e. a positive association with the odds of engaging but no association with minutes of cycling) was also found in a recent study of Kerr *et al.* (2015) (24). A possible explanation for this split association might be that highly connected neighbourhoods cause interrupted cycling and result in only short cycling trips

Table 2 Cycling levels for the different urban regions

	n	Cycling for transport in the last week (%)	Min/week cycling for transport (M ± SD)
a. Ghent region (Belgium)	1,373	56.7	188.8 ± 283.2 [b,c,e]
b. Paris region (France)	687	13.4	28.3 ± 108.0 [a,c,d]
c. Greater Budapest (Hungary)	740	30.9	68.2 ± 159.0 [a,c,d]
d. Randstad region (the Netherlands)	1,138	71.1	193.1 ± 242.7 [b,c,e]
e. Greater London (UK)	641	14.4	43.8 ± 150.4 [a,d]

The superscript letters indicate which urban regions significantly differ from each other ($p < 0.05$).

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

	Logistic model† (n = 3,338; AIC = 3870.7)		Gamma model‡ (n = 1,628; AIC = 1526.4)	
Main effects	OR of engaging in cycling for transport (95% CI)	p-value	Exp B§ (95% CI)	p-value
Presence of cycle paths	1.10 (1.00, 1.21)	0.051	1.04 (0.98, 1.10)	0.225
Good maintained cycle paths	0.97 (0.89, 1.07)	0.534	0.97 (0.92, 1.03)^	0.362
Pleasant environment to walk/cycle	1.00 (0.90, 1.11)	0.993	0.90 (0.82, 0.99)* ^	0.028
Free from litter, graffiti and trash	0.94 (0.86, 1.01)	0.103	0.99 (0.95, 1.04)	0.763
Low traffic speed	1.10 (1.01, 1.19)*	0.028	1.04 (0.99, 1.10)	0.097
Choice between different routes to walk/cycle	1.38 (1.15, 1.65)*** ^	<0.001	1.00 (0.90, 1.11)	0.943
No busy traffic	1.08 (1.00, 1.17)	0.058	1.00 (0.95, 1.05)	0.979
No air pollution	0.81 (0.72, 0.90)*** ^	<0.001	0.94 (0.90, 0.99)*	0.044
Low level of crime	1.03 (0.95, 1.12)	0.505	1.00 (0.95, 1.06)	0.964
Moderating effects				
No air pollution x gender	1.19 (1.05, 1.36)*	0.007		
Choice between different routes x regions	0.94 (0.88, 1.00)	0.063		
Free from litter, graffiti and trash x age			1.00 (0.950, 1.06)	0.163
Good maintained cycle paths x age			1.00 (1.00, 1.01)	0.054
No busy traffic x age			1.00 (1.00, 1.00)	0.992
No air pollution x age			1.00 (1.00, 1.01)	0.107
Pleasant environment to walk/cycle x education			1.12 (1.00, 1.26)	0.051
Choice between different routes x education			1.06 (0.93, 1.21)	0.375

^variable which is significantly moderated;
†The logistic model estimates the association between the independent variables (physical environmental factors) and the odds of engaging in cycling for transport;
‡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;
§Exp B, exponent of B, all gamma models were fitted using a log link function, the exponent of B can be interpreted as the proportional increase of the dependent variable with a one-unit increase in the independent variable;
*$p < 0.05$,
**$p < 0.01$,
***$p < 0.001$;
OR = odds ratio; CI = confidence interval; AIC, Akaike's information criterion.

(24). Lastly, a more pleasant environment for walking or cycling was associated with fewer minutes of cycling per week. Again, this may be the result of reverse causality, i.e. people who cycled more in their neighbourhood may have been more aware of the less pleasant attributes for walking or cycling in their neighbourhood.

If these results are replicated by other (longitudinal or experimental) studies, this might indicate that interventions focusing on reducing traffic speed in city centres would promote increased levels of cycling. Despite the fact that our study showed no negative association between perceived air pollution and cycling for transport, policymakers should be aware of the problem concerning air pollution in those dense areas and should be encouraged to reduce exposure to air pollution for cyclists to improve public health (64,65). Only few moderating effects were found in this study, which indicates that despite significant differences in cycling levels across regions, generic interventions could benefit most population subgroups, even across regions in the different countries included in the present study.

Strengths of this study include the large study sample, distributed across five different countries in Europe. This study addresses a clear evidence gap because there is very limited evidence on the perceived neighbourhood environment correlates of cycling for transport compared with the correlates for walking, leisure-time physical activity or total physical activity. In addition, it is also important for future research to investigate the importance of the objective environment regarding cycling for transport because these environments (objective vs. perceived) are related differently to physical activity (32). A recent review of Ding *et al.*(34) suggests that future studies, if possible, should combine both objective and perceived measurement modes in one study, to compare and contrast the impact of these methods.

A limitation of the current study was the cross-sectional design, which precluded determination of causality. Longitudinal designs enable causal inference with regard to the impact of physical environmental factors on cycling for transport (22,66). Furthermore, the response rate (around 10.8%) was low with the lowest response rates observed in low SES neighbourhoods in comparison with high SES neighbourhoods, which calls into question the external validity and the potential for bias for this study. In addition, this might be a possible explanation for the few moderating effects found in this analysis.

Conclusions

This study indicated that cycling for transport is significantly associated with different perceived physical environmental neighbourhood factors, i.e. more polluted neighbourhoods, better connected neighbourhoods, lower traffic speed levels and neighbourhoods that are less pleasant to walk or cycle in, in five urban regions across Europe. Our results indicated that the majority of the outcomes from the present study were valid for all subgroups, even across regions in the different countries included in the present study.

Authors' contributions

The WP3 SPOTLIGHT group (S. C., J. L., J. M., H. B., H. R., K. G. and J. M. O.) developed the questionnaire, research protocol and conducted the data collection. L. M. performed the data analysis and drafted the manuscript supervised by S. C., F. G., B. D., I. D. B. All other co-authors critically reviewed and revised versions of the manuscript, and each of them read and approved the final manuscript.

Declaration of interests

The authors have no conflicts of interest to declare.

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