

RESEARCH ARTICLE

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# Active living neighborhoods: is neighborhood walkability a key element for Belgian adolescents?

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## Abstract

**Background:** In adult research, neighborhood walkability has been acknowledged as an important construct among the built environmental correlates of physical activity. Research into this association has only recently been extended to adolescents and the current empirical evidence is not consistent. This study investigated whether neighborhood walkability and neighborhood socioeconomic status (SES) are associated with physical activity among Belgian adolescents and whether the association between neighborhood walkability and physical activity is moderated by neighborhood SES and gender.

**Methods:** In Ghent (Belgium), 32 neighborhoods were selected based on GIS-based walkability and SES derived from census data. In total, 637 adolescents (aged 13-15 year, 49.6% male) participated in the study. Physical activity was assessed using accelerometers and the Flemish Physical Activity Questionnaire. To analyze the associations between neighborhood walkability, neighborhood SES and individual physical activity, multivariate multi-level regression analyses were conducted.

**Results:** Only in low-SES neighborhoods, neighborhood walkability was positively associated with accelerometer-based moderate to vigorous physical activity and the average activity level expressed in counts/minute. For active transport to and from school, cycling for transport during leisure time and sport during leisure time no association with neighborhood walkability nor, with neighborhood SES was found. For walking for transport during leisure time a negative association with neighborhood SES was found. Gender did not moderate the associations of neighborhood walkability and SES with adolescent physical activity.

**Conclusions:** Neighborhood walkability was related to accelerometer-based physical activity only among adolescent boys and girls living in low-SES neighborhoods. The relation of built environment to adolescent physical activity may depend on the context.

## Background

Increasing physical activity in youth is one of the key public health strategies to conquer the alarming rise of overweight, obesity and a cluster of risk factors associated with cardiovascular disease and type 2 diabetes [1,2]. To achieve substantial health benefits for school-aged youth, participation in physical activity of at least moderate to vigorous intensity for a minimum of 60

minutes per day is recommended [3,4]. A large proportion of school-aged youth does not achieve the public health recommendations [5-8]. In addition, adolescence is marked by a decline in time spent in physical activity which is more apparent in adolescent boys than in adolescent girls [9-11].

Ecological models provide a framework for understanding the multiple facets that influence physical activity. From the perspective of ecological models, an interwoven relationship between individual and psychosocial, sociocultural, policy and physical environmental factors influences behaviors [12]. Past research has

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identified demographic (e.g. age, gender, pubertal status), psychosocial (e.g. self-efficacy, perceived competence, parental and peer support), sociocultural (e.g. ethnicity) and policy (e.g. extracurricular physical activity) correlates of physical activity among adolescents [13-17]. More recently, the importance of the physical environment as an opportunity to shape physical activity has been established [18-21].

An important construct among the physical environmental correlates is neighborhood "walkability". Neighborhoods considered walkable are characterized by mixed land use, well-connected streets and high residential density [22,23]. These elements are synergistic and can be objectively determined using Geographic Information Systems (GIS) software [24]. The research into the relationship between neighborhood walkability and physical activity has only recently been extended to young people and the current empirical evidence is not consistent [25-28]. The review of Ding et al. [29] established that in only 20% of the studies that investigated the association between objectively determined neighborhood walkability and objectively determined physical activity among adolescents, a positive association was found. Ding et al. stated that when investigating the association between neighborhood environment and youth physical activity, conclusions based on objectively measured environmental attributes seem more credible because of the lower measurement error associated with objective measures. Furthermore, it was stated that self-reported physical activity that captures specific domains of activity allow for tests of association between conceptually matched environmental and physical activity variables.

In research on adults, neighborhood "walkability" has been supported as a key construct among the built environmental determinants. Four studies with a similar design investigated the relationship between objectively determined neighborhood walkability and physical activity in adults: the Neighborhood Quality of Life Study (NQLS) conducted in the US [30], the Physical activity in Localities and Community Environments (PLACE) study conducted in Australia [31], the Belgian Environmental Physical Activity Study (BEPAS) [32] and the Swedish Neighborhood and Physical activity (SNAP) study [33]. The four studies examined neighborhood socio-economic status (SES) as a possible moderator of the association between neighborhood walkability and physical activity. For each study, participants were recruited from "quadrants" of neighborhoods; low-SES/high-walkable, low-SES/low-walkable, high-SES/high-walkable and high-SES/low-walkable neighborhoods were defined to ensure diversity of environments. Living in neighborhoods characterized by higher walkability was found to be associated with more walking for

transport [30-33], more cycling for transport [32], more walking for leisure [30,32,33] and more accelerometer-based moderate to vigorous physical activity [30,32,33].

The results of the four studies concerning the moderating effect of neighborhood SES on the association between neighborhood walkability and physical activity were not totally comparable. In NQLS, the association between neighborhood "walkability" and walking for transport was stronger in high-SES than in low-SES neighborhoods [30]. In PLACE, BEPAS and SNAP the benefits from neighborhood "walkability" were similar in high- and low-SES neighborhoods [31-33].

The results of studies in youth, investigating the direct association between neighborhood SES and physical activity, showed a positive association between neighborhood SES and physical activity [34-36]. However, to our knowledge, the study of Kerr et al. [37] was the only study investigating the interaction between neighborhood walkability and neighborhood SES in youth. The results of this US study revealed that physical activity behavior of 5-18 year olds reported by the parents was related to objectively determined neighborhood walkability in high-income neighborhoods and not in low-income neighborhoods.

Considering the discrepancies in needs and behaviors between adults and youth, the relationships found in adults may not be generalisable to youth. Youth are dependent on adult rules governing travel and destination choices and are not licensed to use motor vehicles under the age of 16. Consequently, they are more captive in their own neighborhood, and the influence of local neighborhood environmental attributes may be more pronounced in youth. Therefore, to design an active living neighborhood built environment suitable for both youth and adults, urban planners should know whether and how neighborhood walkability is related to physical activity among adolescent boys and girls.

The aims of the Belgian Environmental Physical Activity study in Youth (BEPAS-Y) were (A) to investigate the association between neighborhood walkability, neighborhood SES and physical activity in youth (B) to investigate whether the association between neighborhood walkability and physical activity is moderated by neighborhood SES and gender.

## Methods

BEPAS-Y was a cross-sectional study conducted in Ghent. Ghent, the capital of the Belgian province East-Flanders occupies over 156.18 sq km (60.3 sq miles) with 1,554.40 inhabitants per sq km (2009). The research protocol of BEPAS in adults [32], which builds on the protocols of NQLS [30] and PLACE [31], was used as template for BEPAS-Y. BEPAS-Y received

approval from the Ethics Committee of Ghent University Hospital.

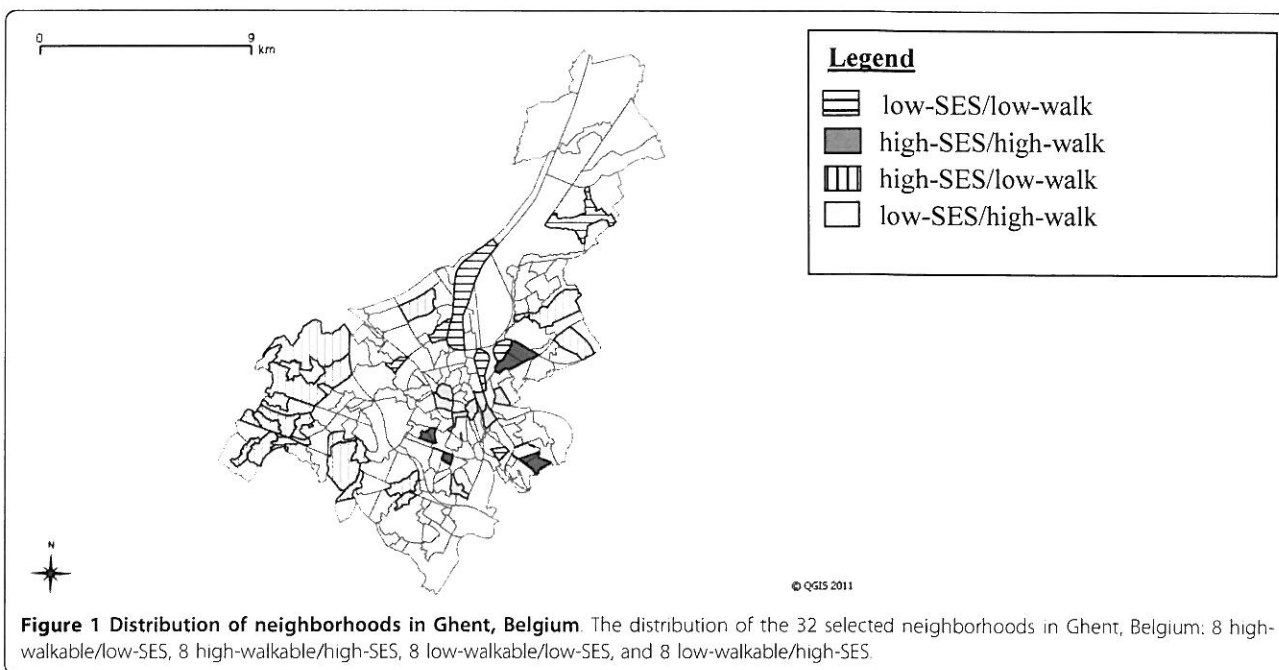
### Selection neighborhoods

Ghent consists of 201 statistical sectors, the smallest administrative entities for which statistical data produced by the Belgian National Institute of Statistics (NIS) are available. Belgian census data derived from the NIS were used to define SES, and geographical information derived from the available GIS databases was used to define walkability. To obtain neighborhoods with a sufficient number of inhabitants as a recruitment pool (approximately 1,000) [30,32], adjacent statistical sectors characterized by comparable walkability (within the same quartile based on the walkability index) and SES (within the same decile based on the median annual household income) were used to define a neighborhood. Consequently, the geographical area of low-walkable neighborhoods was larger than of high-walkable neighborhoods (1.8 km<sup>2</sup> vs. 0.4 km<sup>2</sup>), and the average population density was lower (1535.6 inhabitants/km<sup>2</sup> vs. 6201.2 inhabitants/km<sup>2</sup>). The selection process involved two steps: 1) the statistical sectors were stratified on neighborhood walkability (GIS-based) and SES and 2) neighborhoods (one or more adjacent statistical sectors) meeting criteria for high/low walkability and high/low SES were identified. The selection resulted in 32 neighborhoods: 8 high-walkable/low-SES, 8 high-walkable/high-SES, 8 low-walkable/low-SES, and 8 low-walkable/high-SES (Figure 1). Each neighborhood comprised 1-5 contiguous statistical sectors.

### Neighborhood walkability

For each statistical sector a walkability index was calculated using three objective GIS-based measures: residential density, intersection density, and land use mix, which have been consistently related to physical activity [38,39]. Geographical cadastral data (residential land use, street centerline data, zoning data) and census data provided by the Service for Environmental Planning in Ghent were integrated in a GIS database and used to determine the walkability components.

Net residential density represents the ratio of residential units to the land area devoted to residential use per statistical sector. Connectivity is the ratio between the number of true intersections (three or more legs) to the land area of each statistical sector. Land use mix is an indication of the degree to which a diversity of land use types were present in each statistical sector. Five land uses were considered: residential, retail (supermarkets, bakeries, butchers, banks, and clothing shops), office, institutional, and recreational (sport and non-sport). The corresponding values were normalized and z-scores were calculated. The three-component walkability-index was created by weighing the z-scores of the environmental features, using the following expression: walkability = (2\*z-connectivity) + (z-residential density) + (z-land use mix). The formula used is an adapted version of the formula of Frank and colleagues [40]. Because no GIS data were available, "retail floor area ratio" was omitted from the formula. Based on their walkability index, the statistical sectors were ranked and quartiles were constructed. The highest quartile constituted the



high-walkable sectors, the lowest quartile the low-walkable sectors.

#### **Neighborhood SES**

The socioeconomic environment of each statistical sector was defined in terms of the median annual household income, using data from the NIS (Belgium, 2008). Corresponding to their income data, the statistical sectors were ranked and divided into deciles. Outliers were avoided by excluding sectors with annual household income values less than €11,600 and greater than €116,000. The second, third, and fourth deciles of the ranking contained the low-SES sectors; the seventh, eighth, and ninth deciles the high-SES sectors [32].

#### **Procedure**

After neighborhood selection, the addresses from all, 13-15 year old adolescents ( $n = 1553$ ) living in the selected neighborhoods were acquired by the Public Service of Ghent. Between October 2008 and May 2009 an informative letter about the study with an invitation to participate was posted to the potential participants. One week later, home visits took place. Participants were recruited simultaneously in the four groups of neighborhoods throughout the recruitment period to avoid seasonal bias.

In May 2009, 1,399 adolescents were invited, 1,078 adolescents were found at home and 59.1% ( $n = 637$ ; 49.4% boys) consented to participate. Because at that moment, recruitment goals were achieved with approximately equal numbers of participants within the four groups of neighborhoods, it was decided not to contact the remaining 154 adolescents as they were mostly from high SES neighborhoods. Written consent was obtained from all participants and the adolescents' parents or legal guardian. During the home visit, a questionnaire was delivered and an interview was conducted. The protocol of the accelerometer and non-wear activity diary was explained and an appointment for a second home visit was made to collect the accelerometer, diary and questionnaire.

#### **Measures**

##### **Physical activity**

**Objectively assessed physical activity** Physical activity was objectively assessed using accelerometers, model GT1M (Actigraph MTI, Manufacturing Technology Inc., Pensacola, FL, USA) and model 7,164 (Computer Science Application, Inc., Shalimar, FL, USA). Two recent studies confirmed that the output of accelerometers model GT1M and model 7,164 was similar and that therefore the two models can be used in the same study [41,42]. The adolescents were asked to wear an accelerometer during waking hours, for 7 consecutive days including 2 weekend days. Secured by an elastic

belt, the accelerometers were worn on the right hip, above the iliac crest.

Non-wear time activity diaries were provided to register activities for which the accelerometer was removed (aquatic activities or activities that prohibit an accelerometer). Adolescents recorded on a pre-printed form when the accelerometer was removed, when they put it back on, and the kind of the activities they were involved in [43,44].

Data-reduction software, MeterPlus 4.2. [45], was used to screen, clean and score the accelerometer data. In the data reduction process, time periods of at least one hour of consecutive zeros were removed, assuming the accelerometer was unworn [46,47]. Whenever applicable, these consecutive number of zeros were, after the accelerometer data scoring process, replaced by the corrected number of minutes moderate physical activity and vigorous physical activity registered in the diaries [43,44]. To score the accelerometer data, the thresholds of Puyau (moderate physical activity: 3,200-8,199 counts/min and vigorous physical activity:  $\geq 8,200$  counts/min; respectively corresponding to activities 3-6 MET and activities  $> 6$  MET) [48] were used. For inclusion in the data analysis, the required total accumulated number of minutes registered time by the accelerometer and diaries was 600 minutes for weekdays and 480 minutes for weekend days. Furthermore, 3 valid weekdays and 1 valid weekend day of monitoring were needed to obtain reliable estimates [49-51]. The accelerometer data were used to provide an indication of adolescents physical activity by means of the average activity level expressed in counts/minute (CPM) and mean minutes of moderate to vigorous physical activity per day (MVPA). The average activity level gives an indication of the total level of physical activity and is not dependent of the chosen cut-points. The number of minutes of moderate to vigorous physical activity is an outcome that is relevant for the assessment of activity relative to meeting public health guidelines.

**Self-reported physical activity** The Flemish Physical Activity Questionnaire (FPAQ) [52] (interview version) was used to determine the duration (hours and minutes per day) of specific physical activity behaviors undertaken in specific contexts: school related active transportation (walking and cycling to and from school), walking and cycling for transport during leisure time, and sport during leisure time. The FPAQ was found to be a reliable and reasonably valid questionnaire for the assessment of different dimensions of physical activity in 12-18 year old adolescents [52].

##### **Demographic variables**

Self-reported data included adolescents' gender, age, nationality and SES. Educational attainment and employment of the adolescent' parents were used as a



proxy measure of adolescents' SES. The educational level of the adolescents' mother and father was determined based on four options: less than high school, completed high school, completed college or completed university. The employment status of mother and father (employed, unemployed) was coded into both parents employed, one of the parents employed or both parents unemployed.

### Statistical analyses

To provide information about characteristics of the sample, descriptive statistical analyses were conducted using SPSS 17.0. Tests for normal distribution revealed some skewed physical activity variables. To obtain distributions that more closely approximated symmetry, logarithmic transformations were conducted, and the transformed variables were used in the analyses. For ease of interpretation, summary data of untransformed physical activity variables are reported in minutes/day.

To analyze the associations between neighborhood walkability (dichotomous variable: low/high neighborhood walkability), neighborhood SES (dichotomous variable: low/high neighborhood SES) and physical activity, multivariate regression analyses were conducted using MLwin version 2.22. To examine if the association between neighborhood walkability and physical activity behavior was moderated by neighborhood SES, the

cross-product term "neighborhood walkability × neighborhood SES" was entered in the regression model.

To examine if the association between neighborhood walkability, neighborhood SES and physical activity behavior was moderated by gender, the cross-product terms "neighborhood walkability × gender", "neighborhood SES × gender" and "neighborhood walkability × neighborhood SES × gender" were separately included in the regression model.

All analyses were controlled for three proxy measures of individual SES (parental employment and educational attainment of mother and father) [53]. Clustering of individuals in neighborhoods was taken into account by using multi-level modelling with adolescents at the first level and neighborhoods at the second level. Neighborhood-level attributes (neighborhood walkability and SES) were handled as level-2 variables, individual attributes (physical activity, parental employment and parental education) were handled as level-1 variables.

### Results

From the 637 adolescents who consented for the study, 615 (96.5%) returned a complete physical activity questionnaire, and 513 (80.5%) had complete accelerometer data. Table 1 represents descriptive statistics for demographic characteristics by type of neighborhood. Mean age of the total sample was  $14.6 \pm 0.9$  years, and 50.4%

**Table 1 Descriptive statistics for demographic characteristics by type of neighborhood**

	total (n = 637)	low-SES/low-walk (n = 139)	low-SES/high-walk (n = 158)	high-SES/low-walk (n = 169)	high-SES/high-walk (n = 171)
<b>Age: mean (SD)</b>	14.6 (0.9)	14.5 (0.9)	14.6 (1.0)	14.5 (0.9)	14.6 (0.9)
<b>Gender: %</b>					
Male	49.6	50.4	50.6	47.3	50.3
Female	50.4	49.6	49.4	52.7	49.7%
<b>Educational level: %</b>					
<b>Mother:</b>					
Less than high school	9.9	19.8	16.7	2.0	3.9
Completed high school	25.1	39.7	17.4	28.9	17.5
Completed college	40.4	33.6	31.9	45.6	48.1
Completed University	24.6	6.9	34.1	23.5	30.5
<b>Father:</b>					
Less than high school	7.5	18.6	7.9	2.1	4.0
Completed high school	36.0	54.9	24.6	36.4	31.1
Completed college	26.6	19.5	35.4	30.8	29.1
Completed University	29.8	7.1	42.1	30.8	35.8
<b>Employment status: %</b>					
Both employed	68.5	61.6	56.5	78.8	75.5
One parent unemployed	26.7	29.7	36.4	20.6	20.9
Both unemployed	4.2	8.7	7.1	0.6	3.7

was female. Most adolescents' parents were highly educated, as 60.8% attained college or university, and most parents were both employed (68.5%).

Descriptive statistics for the outcome variables are given in Table 2. The objectively measured accelerometer data revealed that the adolescents engaged in on average 33.0 (23.7) minutes/day of moderate to vigorous physical activity. The objectively determined average activity level was 401.8 (148.5) counts/minute. The adolescents reported on average 9.7 (11.7) minutes/day of walking during leisure time, 8.2 (10.7) minutes/day of cycling during leisure time, 11.5 (14.5) minutes/day of walking and cycling to and from school and 21.8 (24.1) minutes/day of sports during leisure time.

### Associations of physical activity with neighborhood walkability and neighborhood SES

#### Objectively measured physical activity

Among adolescents living in low-SES neighborhoods, we found an association between neighborhood walkability and objectively measured moderate to vigorous physical activity ( $p < 0.01$ ), whereas among adolescents living in high-SES neighborhoods we found no association. In low-SES neighborhoods, adolescents living in high-walkable neighborhoods performed more moderate to vigorous physical activity than adolescents living in low-walkable neighborhoods (34.7 (23.9) minutes/day and 27.2 (19.9) minutes/day respectively). (Table 3 and Figure 2)

Similar to accelerometer-based moderate to vigorous physical activity, we found an association between neighborhood walkability and the objectively determined average activity level expressed in counts/minute among adolescents living in low-SES neighborhoods ( $p < 0.01$ ), whereas among adolescents living in high-SES neighborhoods we found no association. In low-SES neighborhoods, adolescents living in high-walkable neighborhoods achieved a higher average activity level than adolescents living in low-walkable neighborhoods (422.2 (164.0) counts/minute and 382.3 (161.3) counts/minute respectively). (Table 3 and Figure 2)

Analyses of the moderating effect of gender showed that gender did not moderate any association between neighborhood walkability, neighborhood SES and moderate to vigorous physical activity or the average activity level.

#### Self-reported physical activity

For self-reported minutes/day of walking for transport during leisure time we found an association with neighborhood SES ( $p < 0.05$ ). Adolescents living in low-SES neighborhoods reported on average more minutes/day walking for transport during leisure time than adolescents living in high-SES neighborhoods (13.4 min/day (13.8) vs. 6.5 min/day (8.2) respectively). No association between neighborhood walkability and self-reported minutes/day of walking for transport during leisure time was found.

For the reported minutes/day cycling during leisure time, active transport to and from school and sports during leisure time, no association was found with neighborhood walkability nor with neighborhood SES.

Gender did not moderate any association between neighborhood walkability, neighborhood SES and walking for transport during leisure time, cycling during leisure time, active transport to and from school and sports during leisure time.

### Discussion

The main finding of the present study was that for 13-15 year old Belgian adolescent boys and girls the average activity level and the mean minutes moderate to vigorous physical activity per day were associated with neighborhood walkability, but this association was moderated by neighborhood SES. Only in low-SES neighborhoods, adolescent boys and girls living in high-walkable neighborhoods performed more moderate to vigorous physical activity (+ 7.4 min/day) and achieved a higher average activity level (+ 39.9 counts/min) than adolescent boys and girls living in low-walkable neighborhoods. Among adolescents living in high-SES neighborhoods, no association was found between neighborhood walkability and accelerometer-based

**Table 2 Descriptive statistics for the outcome variables for the total group and by type of neighborhood**

	total	low-SES/low-walk	low-SES/high-walk	high-SES/low-walk	high-SES/high-walk
<b>Accelerometer: mean min/day (SD)</b>	<b>(n = 513)</b>	<b>(n = 100)</b>	<b>(n = 137)</b>	<b>(n = 129)</b>	<b>(n = 147)</b>
MVPA	33.0 (23.7)	27.2 (19.9)	34.7 (23.9)	33.9 (22.3)	34.5 (26.4)
Counts/min	401.8 (148.5)	382.3 (161.2)	422.2 (164.0)	395.7 (140.8)	401.3 (128.6)
<b>FPAQ: mean min/day (SD)</b>	<b>(n = 615)</b>	<b>(n = 134)</b>	<b>(n = 150)</b>	<b>(n = 163)</b>	<b>(n = 168)</b>
Walking during leisure time	9.7 (11.7)	13.2 (14.0)	13.7 (13.7)	7.0 (8.8)	6.0 (7.5)
Cycling during leisure time	8.2 (10.7)	8.4 (11.1)	10.5 (12.7)	8.1 (10.2)	6.2 (8.4)
Active transport to and from school	11.5 (14.5)	11.0 (15.4)	13.2 (11.9)	12.1 (18.5)	9.7 (11.1)
Sports participation	21.8 (24.1)	17.9 (23.2)	23.1 (27.8)	22.1 (22.5)	23.6 (22.3)

**Table 3 Multivariate multi-level regression analyses of the association between neighborhood walkability, neighborhood SES and physical activity**

	Objectively measured			Self-reported		
	MVPA	CPM	Active transport to and from school	Walking during leisure time	Cycling during leisure time	Sport during leisure time
<b>MODEL 1</b>						
Educational attainment mother						
<i>less than high school (ref.)</i>						
completed high school	0.124(0.076)	0.036 (0.034)	-0.120(0.125)	-0.206(0.102)	0.063(0.109)	0.234(0.133)
completed college	0.085(0.079)	0.012 (0.035)	-0.027(0.130)	-0.169(0.107)	0.174(0.113)	0.292(0.138)
completed university	0.059(0.086)	0.001 (0.038)	-0.060(0.143)	-0.198(0.117)	0.096(0.124)	0.370(0.152)
Educational attainment father						
<i>less than high school (ref.)</i>						
completed high school	-0.156 (0.084)	-0.053 (0.037)	-0.048(0.129)	-0.030(0.106)	-0.180(0.114)	-0.106(0.141)
completed college	-0.194 (0.090)	-0.053 (0.040)	0.178(0.142)	-0.186(0.116)	-0.118(0.124)	-0.108(0.154)
completed university	-0.184 (0.094)	-0.075 (0.042)	0.015(0.148)	-0.163(0.122)	-0.160(0.130)	-0.145(0.160)
Parental employment						
<i>both parents unemployed (ref.)</i>						
one of the parents employed	0.078(0.100)	0.044 (0.044)	0.313(0.154)	-0.122(0.131)	0.169(0.134)	-0.162(0.166)
Both parents employed	0.206(0.098)	0.083 (0.044)	0.458(0.152)	-0.151(0.129)	0.206(0.132)	0.048(0.163)
<b>WALK</b>						
<i>low-walk (ref.)</i>						
<b>high-walk</b>	<b>0.091 (0.035)*</b>	<b>0.053 (0.017)**</b>	<b>0.151(0.81)</b>	<b>0.131(0.099)</b>	<b>-0.014(0.067)</b>	<b>0.096(0.073)</b>
<b>MODEL 2</b>						
Educational attainment mother						
<i>less than high school (ref.)</i>						
completed high school	0.090(0.077)	0.024 (0.034)	-0.123(0.125)	-0.211(0.102)	0.074(0.109)	0.201(0.133)
completed college	0.064(0.080)	0.007 (0.036)	-0.009(0.131)	-0.160(0.107)	0.187(0.113)	0.263(0.139)
completed university	0.044(0.087)	-0.000 (0.039)	-0.036(0.143)	-0.185(0.118)	0.107(0.124)	0.350(0.153)
Educational attainment father						
<i>less than high school (ref.)</i>						
completed high school	-0.155 (0.085)	-0.051 (0.038)	-0.035(0.129)	-0.025(0.106)	-0.176(0.114)	-0.105(0.141)
completed college	-0.192 (0.091)	-0.050 (0.041)	0.205(0.142)	-0.175(0.117)	-0.111(0.124)	-0.105(0.153)
completed university	-0.173 (0.094)	-0.067 (0.042)	0.049(0.148)	-0.146(0.122)	-0.154(0.129)	-0.134(0.159)

**Table 3 Multivariate multi-level regression analyses of the association between neighborhood walkability, neighborhood SES and physical activity (Continued)**

Parental employment						
<i>both parents unemployed (ref.)</i>						
one of the parents employed	0.057(0.101)	0.037(0.045)	0.317(0.154)	-0.117(0.130)	0.179(0.134)	-0.178(0.166)
Both parents employed	0.179(0.099)	0.073(0.044)	0.464(0.152)	-0.146(0.129)	0.220(0.132)	0.022(0.163)
<b>SES</b>						
<i>low-SES (ref.)</i>						
<b>high-SES</b>	<b>0.059(0.037)</b>	<b>0.013(0.018)</b>	<b>-0.154(0.081)</b>	<b>-0.189(0.093)*</b>	<b>-0.083(0.065)</b>	<b>0.102(0.073)</b>
<b>MODEL 2</b>						
Educational attainment mother						
<i>less than high school (ref.)</i>						
completed high school	0.121(0.075)	0.035(0.034)	-0.101(0.125)	-0.193(0.102)	0.079(0.109)	0.217(0.134)
completed college	0.081(0.078)	0.011(0.035)	-0.001(0.130)	-0.150(0.107)	0.194(0.113)	0.267(0.139)
completed university	0.050(0.085)	-0.001(0.035)	-0.037(0.143)	-0.180(0.117)	0.113(0.124)	0.347(0.152)
Educational attainment father						
<i>less than high school (ref.)</i>						
completed high school	-0.185(0.083)	-0.061(0.037)	-0.047(0.129)	-0.034(0.106)	-0.184(0.114)	-0.111(0.141)
completed college	-0.238(0.090)	-0.065(0.040)	0.185(0.143)	-0.192(0.117)	-0.125(0.125)	-0.118(0.155)
completed university	-0.237(0.093)	-0.089(0.042)	0.019(0.149)	-0.172(0.122)	-0.171(0.131)	-0.153(0.162)
Parental employment						
<i>both parents unemployed (ref.)</i>						
one of the parents employed	0.062(0.099)	0.040(0.044)	0.319(0.153)	-0.121(0.130)	0.171(0.134)	-0.171(0.166)
Both parents employed	0.187(0.097)	0.077(0.044)	0.474(0.151)	-0.145(0.129)	0.217(0.132)	0.032(0.163)
WALK						
<i>low-walk (ref.)</i>						
high-walk	0.230(0.053)	0.098(0.026)	0.193(0.113)	0.245(0.129)	0.075(0.092)	0.097(0.107)
SES						
<i>low-SES (ref.)</i>						
high-SES	0.187(0.052)	0.057(0.025)	-0.103(0.108)	-0.052(0.132)	0.003(0.090)	0.102(0.103)
<b>WALK × SES</b>	<b>-0.228(0.068)***</b>	<b>-0.073(0.034)*</b>	<b>-0.089(0.149)</b>	<b>-0.262(0.182)</b>	<b>-0.170(0.123)</b>	<b>0.005(0.140)</b>

Model 1,2 and 3 were corrected for educational attainment mother and father and parental employment

\*p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

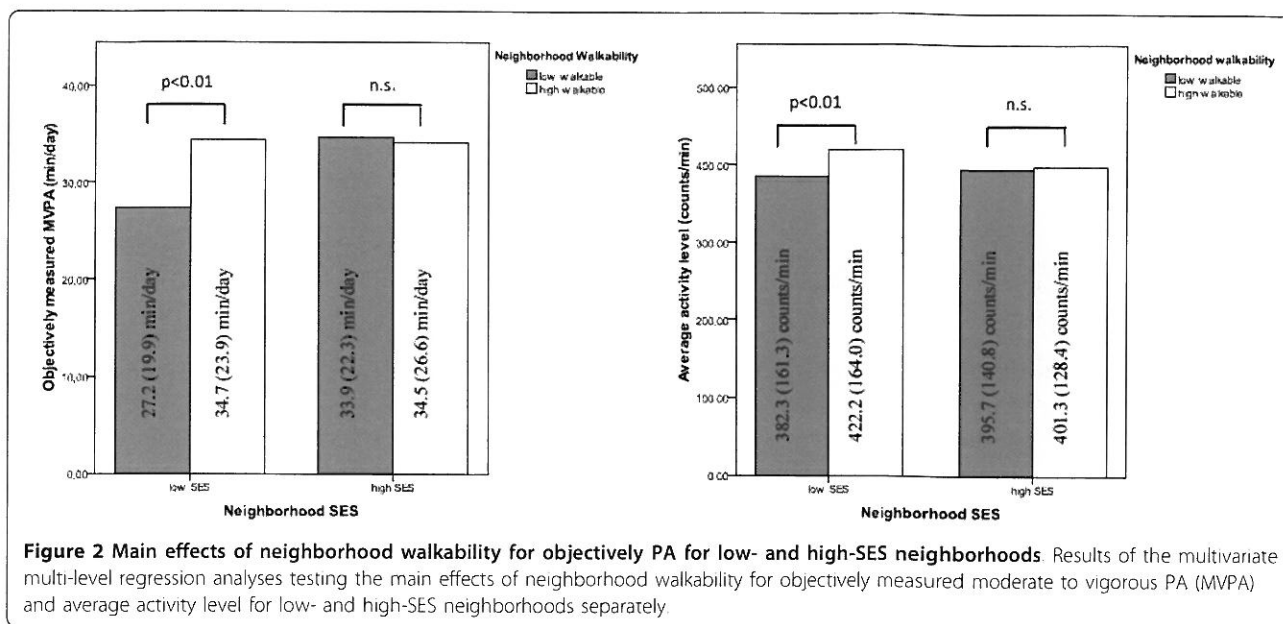
<sup>1</sup> WALK: neighborhood walkability (low/high neighborhood walkability)

<sup>2</sup> SES: neighborhood socio-economic status (low/high neighborhood SES)

<sup>3</sup> MVPA: moderate to vigorous physical activity

<sup>4</sup> CPM: counts/minute





physical activity. For the self-reported variables-active transport to and from school, walking and cycling for transport during leisure time and sport during leisure time-no association with neighborhood walkability was found. These results are an indication that the main conclusion of the PLACE, NQLS, BEPAS and SNAP studies, that adults living in high-walkable neighborhoods reach higher levels of physical activity, cannot be extended to the overall group of 13-15 year old Belgian adolescents.

The contrasting results of the BEPAS-Y and the BEPAS adult [32] studies, conducted in the same neighbourhoods, are in particular noteworthy. The BEPAS adult study documents large differences in accelerometer-based moderate to vigorous physical activity across walkability groups, in both low- and high-SES neighborhoods. Given the similarity of environments and measures, questions can be raised about the different responses of adolescents and adults to their built environment.

Neighbourhood "walkability" refers to the ability to walk or cycle to nearby destinations. The key elements of "walkability" are determined based on adult research investigating the specific neighborhood environmental attributes that are associated with higher levels of walking and cycling for transport [38,39]. Walkability has been consistently found to be associated with walking for transport on three continents so far [30-33,54], as well as with cycling for transport [32]. In comparison with adult physical activity behavior, adolescent physical activity behavior is characterized by a larger variation in types of physical activity. Active transport forms only a fraction of adolescents' total physical activity behavior.

Given this, the possibility exists that the construct "walkability" is not as relevant for adolescents. In the current evidence-base, the specific built environmental attributes that characterize a walkable neighborhood, are less consistently associated with adolescents' physical activity [29]. In some adolescent studies connectivity even showed an inverse association with physical activity [29]. Including connectivity in the walkability-index for adolescents could therefore negate some of the effects.

Considering the multidimensional character of neighborhood environments, it could be that among youth, other built environment attributes are the key elements of neighborhoods conducive to an active lifestyle. It could also be that family rules could interact with built environment and social environment features in influencing adolescent physical activity. Thus, further studies are needed to determine the specific environmental attributes characterizing the ability for youth to be active in a neighborhood. Parallel to research in adults, those attributes can be used to create an index that refers to the ability of youth to be active in their neighborhood, e.g. an "activability" index.

In the development of an "activability" index for youth it may be advisable to take into account the diverse physical activity domains adolescents are participating in. As stated by Giles-Corti et al. [55] environmental attributes are expected to have effects that vary by physical activity domain. In particular, walkability is expected to be related to active transportation, and a recent review confirms that proximity to parks and recreation facilities was one of the most consistent correlates of adolescent physical activity [29]. The present study did not include measures of recreation environments expected to be

related to leisure time physical activity. Thus, an “activeness” index likely needs to include recreation environment attributes as well. Due to large variations in built environments across countries and continents, an “activeness” index may need to be tailored to each context. Research to identify built environmental attributes that have beneficial effects on physical activity in adults and youth is of utmost importance to inform policy makers and urban planners in making well-considered decisions concerning built environmental redevelopments of existing neighborhoods and planning of new neighborhoods.

Surprisingly, previous studies that found an interaction between neighborhood walkability and neighborhood SES showed a stronger association between neighborhood walkability and physical activity in high-income neighborhoods [31,37]. Part of the explanation for the interaction found in the present study may be attributed to economic factors. As stated by Stalsberg et al. [56] the observed SES moderating effect could be explained by varying ability to deal with the financial outlay that certain activities require (e.g. sport material, membership fees). Most adolescents living in high-SES neighborhoods have the ability to participate in activities that require financial outlay, in contrast to adolescents living in low-SES neighborhoods. Consequently, adolescents from high-SES neighborhoods are less dependent on their neighborhood environment to be active than their peer group from low-SES neighborhoods. This explanation is supported by the objectively measured levels of physical activity. The average activity level and mean number of minutes moderate to vigorous physical activity were lowest in the low-SES/low-walkable neighborhoods. Since there is evidence that low-SES adolescents often have lower levels of physical activity [57,58] and that SES shows a clear inverse relationship with levels of overweight and obesity [59,60], the present study’s findings involve several implications for public policy and the results may be important for future environmental interventions or governmental initiatives. Improving income and education in low-SES communities is an ultimate solution. However, interim improvements can be based on emerging findings in the US that low-SES neighborhoods have numerous environmental deficits that are not reflected in walkability [61,62]. Low-income neighborhoods, regardless of walkability, were disadvantaged in access to recreation facilities, walking/cycling facilities, aesthetics, pedestrian/traffic safety, and crime safety [62]. Thus, if such environmental disparities are documented in Belgium, interventions could be targeted at low-income neighborhoods to provide more recreation facilities, improve walking/cycling facilities, enhance aesthetics by planting trees and removing graffiti, increase safety of street crossing, and institute more effective crime control methods. Walking for transport

during leisure time was the only outcome for which an association with neighbourhood SES was found. Adolescent boys and girls living in low-SES neighbourhoods reported twice as much walking during leisure time than adolescent boys and girls living in high-SES neighbourhoods (13.4 (13.8) min/day vs. 6.5 (8.2) min/day). As stated by Ross et al. (2008), neighborhoods characterized by a higher level of poverty may have a culture in which people are outside on the streets, walk to visit someone, talk out on the street or just hang out on the street [53]. This culture may encourage adolescents to walk for transport during leisure time. Another possible explanation is that lower-SES households have less access to automobiles. The lack of association between neighborhood SES and the other physical activity variables may be explained by a finding by Voorhees et al. [36]. In that study no association was found between SES and accelerometer-based physical activity in adolescent girls. However, some qualitative differences in types and location of activities between low- and high-SES girls were found. Lower-SES girls achieved higher levels of moderate to vigorous physical activity at home whereas higher-SES girls were more likely to participate in moderate to vigorous physical activity at school or community facilities. Furthermore, low-SES girls reported less moderate to vigorous physical activity in organized activity and were more involved in informal and spontaneous activities in comparison with high-SES girls. The Voorhees et al. (2009) results indicate that low-SES girls do more of their physical activity near home, suggesting that neighborhood environments could be more important for low-SES adolescents.

#### Limitations and strengths

Limitations of the present study included the cross-sectional study design which does not permit causal inferences. Second, despite stratified recruitment in higher- and lower-SES neighborhoods, education levels of parents were generally high. This likely reflects both high education levels of the university city and some recruitment bias. Third, neighborhoods were defined using existing statistical sectors. In that way artificial neighborhoods were created. A possible consequence of this method is that those artificial neighborhoods are not compatible with how respondents would define their own neighborhood. Neighborhood-level indicators of walkability and SES are relatively crude indicators, and individual buffers may more accurately reflect the environments that adolescents are exposed to. Strengths of the present study included the use of both objective and self-reported measures of physical activity. The average activity level, expressed in accelerometer counts/minute, gives an indication of the total level of physical activity. This outcome is based on the raw data provided by the

accelerometer and is not dependent of processing differences. The FPAQ was used to collect information about adolescents' physical activity behavior in diverse domains. Questionnaire answers may be biased by social desirability, but to reduce over reporting, interviewers were trained to question high reports. Second, GIS databases were used to identify neighborhoods that maximized variation in walkability, and Belgian census data were used to identify neighborhoods of low and high-SES. Third, this study included a large sample of adolescent boys and girls. Finally, the study design and protocol was similar to PLACE, BEPAS, NQLS and SNAP studies in adults and importantly was conducted in the same neighborhoods as the BEPAS Adult study.

## Conclusions

The main conclusion of the BEPAS-Youth was that overall, in adolescent boys and girls aged 13-15 years, the association between neighborhood walkability and physical activity depended on neighborhood SES. There was an association between neighborhood walkability and objectively measured physical activity only among girls and boys living in low-SES neighborhoods. The discrepancies between the results of this study of adolescents, a similar study of Belgian adults, and the results of previous international studies in adults and adolescents highlight the need to strengthen the evidence among adolescents. Generally, built environment attributes are less consistently related to physical activity of adolescents than adults. Future investigations should determine the key environmental attributes of an active living neighborhood with a particular relevance for youth. Based on those key attributes, an important next step is to create an "activability" index for youth, which could be used for research and to identify neighborhoods that are less supportive of physical activity and in need of interventions.

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## Authors' contributions

All authors have made substantial contributions to the design of the study. FDM collected the data, conducted the statistical analysis and drafted the

manuscript. DVD, GC, IDB and BD helped to prepare the data collection, provided feedback during the process, participated in the interpretation of the data and provided critical comments on the manuscript. JFS revised the draft for important intellectual content. All authors read and approved the final version of the manuscript.

## Competing interests

The authors declare that they have no competing interests.

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