Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study

Regina Grazuleviciene a,*, Asta Danileviciute a, Audrius Dedele a, Jone Vencloviene a, Sandra Andrusaityte a, Inga Uždanaviciute a, Mark J. Nieuwenhuijsen b, c, d

a Department of Environmental Science, Vytautas Magnus University, K. Donelaičio 58, Kaunas 44248, Lithuania
b Centre for Research in Environmental Epidemiology (CREAL), Doctor Aiguader 88, Barcelona 08003, Spain
c Universitat Pompeu Fabra (UPF), Barcelona, Spain
d Centro de Investigación Biomédica en Red de Epidemiología y Salud Pública (CIBERESP), Madrid, Spain

A R T I C L E   I N F O

Article history:
Received 13 January 2015
Received in revised form 11 February 2015
Accepted 15 February 2015

Keywords:
Green space
Surrounding greenness
Distance to park
Adverse pregnancy outcomes
Effect modification

A B S T R A C T

There is increasing evidence that green space can improve the health and well-being of urban residents. However, there has been no consistent evidence of the effect on reproductive health. We investigated whether surrounding greenness levels and/or distance to city parks affect birth outcomes. This study was based on 3292 singleton live-births from the Kaunas birth cohort, Lithuania (2007–2009), who were enrolled in the FP7 PHENOTYPE project study. Residential surrounding greenness level was ascertained as average of satellite-based normalized difference vegetation index (NDVI) within buffers of 100 m, 300 m, and 500 m of each maternal home and distance to a city park was defined as distance to boundaries of the nearest city park. For each indicator of green space exposure, linear or logistic regression models were constructed to estimate change in birth outcomes adjusted for relevant covariates. An increase in distance to a city park was associated with an increase in risk of preterm birth and decrease of gestational age. We found a statistically significant association between low surrounding greenness and term low birth weight. After assessing effect modification based on the low surrounding greenness (NDVI-500 < median) and the distance to city parks (>1000 m), we found increased risks for low birth weight (OR 2.23, 1.20–4.15), term low birth weight (OR 2.97, 1.04–8.45) and preterm birth (OR 1.77, 1.10–2.81) for subjects with low surrounding greenness and farther distance from a park. Both higher surrounding greenness level and proximity to park have beneficial effects on pregnancy outcomes. A beneficial park effect on foetal growth is most apparent in the environment with low surrounding greenness level. Further investigation is needed to confirm this association.

© 2015 The Authors. Published by Elsevier GmbH. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

A number of epidemiological studies have shown an environmental effect on reproductive health and pregnancy outcomes. It has been shown that women’s health and pregnancy outcomes may be affected by many environmental factors, including the living environment, social status, noise, and chemical pollutants (Agay-Shay et al., 2014; Blumenshine et al., 2010; Stillerman et al., 2008). A recent meta-analysis of the results of the environmental exposures and pregnancy outcomes reported statistically significant associations between environmental exposures such as environmental tobacco smoke, air pollution and chemicals and pregnancy outcomes (Nieuwenhuijsen et al., 2013). However, only a limited number of studies have reported impacts of green spaces on birth outcomes (Dadvand et al., 2012a; Donovan et al., 2011; Hystad et al., 2014; Laurent et al., 2013), and only for surrounding greenness and birth weight they all appear to go in the same direction although there is heterogeneity in effect sizes (Agay-Shay et al., 2014; Dadvand et al., 2014). Strongest associations were found for more deprived individuals for highest residential surrounding greenness and this association varied between different ethnic and socioeconomic groups. A recently published study (Laurent et al., 2013) has shown an increase in birth weight and a reduction in preterm birth associated with

Please cite this article in press as: Grazuleviciene, R., et al., Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study. Int. J. Hyg. Environ. Health (2015), http://dx.doi.org/10.1016/j.ijheh.2015.02.004

1438-4639/© 2015 The Authors. Published by Elsevier GmbH. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
higher residential greenness, whereas other study reported no association of foetal growth with the presence of green spaces in neighbourhood (Markevych et al., 2014).

Poor foetal growth is a marker for the foetal environment and maternal psychological distress, and anxiety may have impact on changes in fetoplacental blood flow (Roos et al., 2014). The findings emphasize a growing appreciation of the potential importance of psychological well-being during pregnancy for infant development. Moreover, foetal growth rate is negatively associated with developmental delay and behaviour problems in children (Chatterji et al., 2014).

While the published studies have found that pregnancy outcomes may be related to the neighbourhood greenness assesses as average of satellite-based normalized difference vegetation index (NDVI) or proximity to parks, these findings are not consistent with respect to the magnitude of the effect on different adverse birth outcomes. All these studies analysed separate effect of residential surrounding greenness level (NDVI) and effect of distance to city parks on birth outcomes.

This study was conducted as part of the positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE project funded by the European Commission Seventh Framework Programme (Nieuwenhuijsen et al., 2014)). To our knowledge, this is the first study to examine the association between residential surrounding greenness, city parks and pregnancy outcomes in the East of Europe, controlling for various maternal characteristics and health parameters. We explored the modifying effect of surrounding greenness evaluating whether the associations of distance to city parks and adverse birth outcomes differ in women residing in areas with different surrounding greenness levels, while controlling for covariates that may influence on studied birth outcomes. In this paper, we hypothesized that the impact of the distance to city parks on adverse birth outcomes depends on the surrounding greenness level in the living environment.

Methods

Study population

This cohort study formed part of the PHENOTYPE green space and health program (Nieuwenhuijsen et al., 2014). The participants were pregnant women recruited between 2007 and 2009 in the city of Kaunas, Lithuania (Gražulevičienė et al., 2011). The women were recruited to the study in the early stages of pregnancy (97% up till 25 weeks). In total, 5202 women were approached; 79% of them agreed to participate in the study. In this green space and pregnancy outcomes study, women with multiple pregnancies (150), those with inconsistent data on the estimation of exposure (mostly, students who moved out of the city during pregnancy, 405), or those for who had not at least one year of residence at their current address (140) were excluded. The analyses here included 3292 female residents of Kaunas that were pregnant and were 20 to 45 years old at the time of the interview, delivered singleton newborn below 4500 g and had complete individual data regarding information on various covariates.

We obtained individual-level covariates through standardized interviews. The questionnaire comprised questions on demographics, chronic diseases (cardiovascular, respiratory, renal, and diabetes), duration of residence, age at inclusion, education, social status, marital status, smoking, alcohol consumption, previous pregnancy outcomes and other potential risk factors for adverse pregnancy outcomes. Women reported their social status at inclusion (worker, student, unemployed – low; housekeeper, officer – medium; manager, company owner – high). The perceived stress by the women was measured by a question: “My daily activities are very tiring and stressful”. The four response options were: “this describes me very well” (1), “fairly well” (2), “not very well” (3), or “not at all” (4), were scored with 1–4 points, and were used to define stress. Values 1 and 2 were considered to represent “stress”, and values 3 or 4 – “no stress”.

The research protocol was approved by the Lithuanian Bioethics Committee and informed consent was obtained from all participants.

Birth outcomes

The data base of this cohort includes a wide range of prospectively collected data on pregnancy outcomes that were obtained through birth certificates. We evaluated gestational age (GA, in weeks), preterm birth (PB, gestation length <37 gestational weeks), birth weight (BW, in g), low birth weight (LBW, birth weight below 2500 g independently of gestational age), term low birth weight (TLBW, birth weight below 2500 g for pregnancies with at least 37 completed weeks of gestation), and small for gestational age (SGA, birth weight below the 10th percentile of birth weight stratified by sex and gestational age in the referent population).

Green space exposure assessment

To estimate surrounding greenness levels, we assigned the normalized difference vegetation index (NDVI) in different buffer sizes. The index represents the level of vegetation or greenness within a Kaunas location and was derived from LANDSAT 5 Thematic Mapper (TM) images at 30 m × 30 m resolution. The map of NDVI was generated using the image that was obtained on 10 July 2011. NDVI provides an indication of the presence and condition of green vegetation. It ranges between −1 and 1 with higher numbers indicating more greenness. The value of “−1” means very high reflectance in the visible red band but with little near-infrared scattering such as from snow or cloud. The values of “−1 to 0” represent no vegetation or water bodies. Grids of major blue space were excluded from the ‘mean NDVI’ calculations, because the cells of coastal water and large inland lakes do not represent accessible areas and including them would lead to a misrepresentative NDVI value. Mean NDVI values of straight-line buffer sizes of 100, 300 and 500 m were calculated as estimations of the level of greenness within the immediately accessible neighbourhood.

Using Urban Atlas data for Kaunas, we estimated proximity to city parks as a straight line distance to the nearest city park. A binary variable was used to assess whether the maternal residential address was within a three (<300 m, 300–1000 m, and >1000 m) buffer sizes from boundaries of a nearest city park. All home addresses of the participants were geocoded and the distance to the nearest city park was estimated. All of the Kaunas city parks that were larger than 1 ha and generally had over 65% of their land covered with trees were regarded as city parks. In this study, to assess the association between the residence distance to city parks and birth outcomes we also used the distance measure as a continuous variable.

Statistical analysis

We applied chi-square test to compare the values and frequencies of baseline maternal characteristics by green space exposures and adverse birth outcomes. The continuous variables are presented as mean value and standard error (SE). Predictor variables whose univariate test showed a statistically significant association (p <0.05) to the outcome were treated as possible risk factors for adverse birth outcome, and were included in the multiple regression models. We used logistic and linear regression.
analyses to estimate associations between residential green space and birth outcomes. The associations are presented corresponding both as a continuous variable per 100 m increase in distance to the nearest city park and exposure measures tertiles. The associations between measures of average NDVI and birth outcomes are presented for different buffer sizes (100, 300 and 500 m) in tertiles and by median. The effects of green space exposure on birth outcomes were estimated as crude and adjusted odds ratios (OR) and regression coefficients with 95% confidence intervals (CI). We adjusted the models for several known covariates that could potentially affect the association between pregnancy outcomes and greenness. For the low birth weight we adjusted for maternal covariates: marital status, education, smoking, alcohol consumption, body mass index, parity, chronic diseases, previous preterm birth, and paternal smoking and infant sex; term low birth weight adjusted for maternal covariates: marital status, education, smoking, alcohol consumption, body mass index, blood pressure, parity, previous preterm birth, and infant sex; preterm birth adjusted for maternal covariates: marital status, education, smoking, renal diseases, stress, previous preterm birth, parity, and paternal smoking; small for gestational age adjusted for maternal covariates: age, marital status, education, social status, smoking, body mass index, parity, and previous preterm birth; birth weight adjusted for maternal covariates: height, smoking, marital status, body mass index, diabetes and chronic hearth diseases, parity, gestation duration, previous preterm birth, and paternal height, and infant sex; gestational age adjusted for maternal covariates: marital status, education, smoking, renal diseases, stress, parity, previous preterm birth, and paternal smoking.

To determine how associations between distance to park and birth outcomes changed based on residential surrounding greenness, effect modification of NDVI-500 m (500 m buffer around each maternal home) median and 1000 m distance to park was assessed by including an interaction term in the logistic regression controlling for covariates that may influence the birth outcomes.

Results

Characteristics of the study population

Of the 3292 singleton births with complete data, 150 (4.6%) were classified as LBW, 51 (1.5%) as term low birth weight, 187 (5.7%) as preterm birth, and 269 (8.2%) as small for gestational age. The mean birth weight was 3450 (SE 2.37) g and mean gestation age was 39.2 (SE 0.03) weeks. Descriptive statistics of the cohort with covariates and exposure information stratified by the median of NDVI are presented in Table 1.

The women recruited were predominantly Lithuanian in ethnic origin (97.4%) and did not smoke (93.1%). The women tended to be highly educated, 54.4% with a university degree. In general, mothers who were single, less educated, had previous preterm history, suffered from a chronic disease or were smoking during pregnancy or were exposed to environment tobacco smoke delivered a higher proportion of low birth weight, term low birth weight and preterm birth infants.

The mean annual residential greenness values of 25th, 50th, and 75th percentiles of the NDVI-100 m buffer were 0.487, 0.545 and 0.594, respectively; in NDVI-300 m they were 0.498, 0.543, and 0.588, respectively; and in NDVI-500 m buffer they were 0.498, 0.546 and 0.587, respectively. About 61.2% of the participants’ homes were within 300–1000 m distance to city parks and 86.5% of all participants home were within a 1000 m (10 min walking distances) buffer size from nearest city park. There were statistically significant differences in the characteristics of the NDVI-100 m versus NDVI-500 m (0.546) buffers environments, with higher levels of air PM2.5 and NO2 concentrations, and noise level.

In a univariate ANOVA analysis, with increasing residence distance to city parks, there was no monotonic relationship between distance to the park and birth weight and gestational age (Table 2). However, in ANCOVA analysis, newborns for whose mother’s house was within 300 m from a city park the birth weight was 3433.0 ± 18.4 g, while when the house was >1000 m from a city park the mean birth weight was 3421.5 ± 25.1 g (p = 0.064). We found a statistically significant lower gestational age among women whose residence was >1000 m from a city park compared to mother’s whose house was within 300 m from a city park (p = 0.045).

Association between green space and birth outcomes

The association between residence distance to the nearest city park and adverse birth outcomes are presented in Table 3. An increase in distance slightly increased risk for low birth weight, however a statistically significant increase was found only for the risk of preterm birth (adjusted OR 1.86, 95% CI 1.18–2.94).

Table 4 shows that NDVI within 100, 300, and 500 m of residences was not associated with low birth weight, preterm birth, small for gestational age, birth weight and gestational age, but that term low birth weight was. When women with the exposure to the highest NDVI tertile were compared with the lowest tertile, surrounding greenness was statistically significantly associated with higher term low birth weight within the NDVI-500 size (OR 3rd/1st tertile = 2.37, 95% CI 1.14–4.95).

Effect modification by surrounding greenness and distance to city parks

Using NDVI-500 > median as a reference category, we estimated the effect of lower surrounding greenness (NDVI-500 < median) on adverse pregnancy outcomes (Table 5). We found an increased risk for term low birth weight associated with surrounding greenness below NDVI-500 median compared to above NDVI-500 median (adjusted OR = 1.92, 95% CI 1.29–3.45). No statistically significant associations were observed with other birth outcomes.

Analysing possible greenness effect modification on pregnancy outcomes, the interaction term included the NDVI-500 > median as a reference, and distance to park as effect modifier. We found an increased adverse impact on pregnancy outcomes among the women residing farther away from park (distance to city park > 1000 m) and with lower surrounding greenness. The effect was statistically significant for increased risk of low birth weight (OR 2.23, 1.20–4.15), term low birth weight (OR 2.97, 1.04–8.45) and preterm birth (OR 1.77, 1.10–2.81) (Table 6). No statistically significant effect was found for gestational age, small for gestational age and birth weight.

Discussion

In this birth cohort study, we found a positive impact of residence close to city parks on birth outcomes: greater distance to city parks was associated with a statistically significant increase in risk of preterm birth and decreased of gestational age. We did not find statistically significant associations between surrounding greenness level measured as NDVI of 100, 300, and 500 m buffer sizes and birth outcomes, except for term low birth weight. We found effect modification for surrounding greenness and distance to parks. These associations were robust to adjustment for covariates that may influence on studied birth outcomes.

Our study is the first to demonstrate an interaction between surrounding greenness as measured by NDVI, residence distance to city parks and birth outcomes. The observed effect modification
showed that the risk of adverse birth outcomes, such as low birth weight, term low birth weight and preterm birth, are higher for women whose residence is in areas with low surrounding greenness (NDVI < 0.500 above and below the median) and distance to a city park is more than 1000 m compared with women whose residence is close to city parks and have high surrounding greenness.

Some of our observed associations between green space and risk of adverse birth outcomes are consistent with the previous studies, while others are in the same direction but not statistically significant. In a cohort study in Vancouver, Canada (Hystad et al., 2014), where the mean annual residential greenness value (NDVI) was 0.24, an interquartile increase in greenness was associated with an increase in term birth weight, decrease in preterm birth and small for gestational age, after adjustment for distance to a park.

A large (more than 80,000 of pregnancy outcomes) study in Southern California (Laurent et al., 2013) reported a reduced risk
of preterm birth and an increase in birth weight in term born infants associated with an increase in NDVI. A Tel Aviv registry-based study (Agay-Shay et al., 2014) reported associations between NDVI interquartile range increase and increased birth weight and decreased risk for low birth weight, while no associations were observed for living within 300 m from major green spaces with gestational age and preterm birth. In four Spanish birth cohorts (Dadvand et al., 2012a) an interquartile range increase in average NDVI in 500 buffer size was associated with increases in birth weight and head circumference, but not with gestational age. A beneficial effect of exposure to green spaces on birth weight was observed among the lowest education level women group exposed to higher surrounding NDVI or living close to major green spaces in Barcelona (Dadvand et al., 2012b).

Donovan et al. (2011) observed a reduction in the risk of small for gestational age associated with higher surrounding tree canopy cover of maternal residential addresses; however, they did not find an association for preterm birth. A birth cohort study in Munich reported an association between interquartile increase of surrounding greenness in a NDVI-500 buffer (mean NDVI was 0.329) with an average birth weight increase of 17.6 g, while there was no association with neighbourhood green spaces in a 500 m distance (Markeych et al., 2014). Similar results were reported in Bradford (mean NDVI-500 0.25): after full adjustment, an interquartile range in surrounding greenness was associated with an 15.8 g increase of birth weight, but there was no statistically significant association between residential proximity to green spaces and birth weight (Dadvand et al., 2014).

There are a few reasons that may explain the differences in the obtained results. Different results in the surrounding greenness exposure and adverse birth outcomes between the studies might be due to the differences in the greenness composition, because NDVI index does not account for differences in the proportion of trees and grass that might have different impact on psycho-emotional stress, psychological restoration and physical activity (Bowler et al., 2010; Lee and Maheswaran, 2011). Surrounding greenness level differences between the studies and differences in correlation between NDVI and major neighbourhood green spaces also may have impact on the association with birth outcomes.

For both NDVI and proximity to city parks, the exact mechanisms behind the associations with pregnancy outcomes remain to be elucidated. Mitchell et al. (2011) proposed that surrounding greenness is more indicative of the impact of greenness on reducing psychophysiological stress, while distance to major green spaces is more suggestive of an effect of physical activity. Both psychophysiological stress and physical activity may have an impact on pregnant women health and pregnancy outcomes. The study of green spaces and pregnancy outcomes in Southern California

| Table 2 |
| Distribution of mean birth weight and gestation age by the distance to city parks. |
| Distance to the park | Birth weight [g] | SE | p* | p† | Gestation age (weeks) | SE | p* | p† |
| <300 m | 3433.0 | 18.4 | 0.196 | 0.064 | 39.19 | 38.1 | 0.040 | 0.045 |
| 300–1000 m | 3462.5 | 11.8 | 39.24 | 24.4 |
| >1000 m | 3421.5 | 25.1 | 39.00 | 48.0 |
| Continuous per 100 m increase β (95% CI) | –0.1(–3.3–3.1) | –0.01(–0.03–0.01) |

1. p-Value in univariate ANOVA.
2. p-Value in ANCOVA (included covariates for BW: maternal and paternal height, maternal active smoking, marital status, infant sex, gestation duration, parity, BMI, previous preterm birth, maternal diabetes and chronic heart diseases; for GA: marital status, education, maternal and paternal smoking, parity, renal diseases, previous preterm birth, and gestational stress).

<p>| Table 3 |
| Crude and adjusted odds ratios (OR) and their 95% confidence intervals (CI) for birth outcomes with different distances to the nearest city park. |</p>
<table>
<thead>
<tr>
<th>Distance to the park</th>
<th>Cases</th>
<th>Controls</th>
<th>Crude OR</th>
<th>95% CI</th>
<th>Adjusted OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBW</td>
<td>&lt;300 m</td>
<td>43</td>
<td>52</td>
<td>789</td>
<td>94.8</td>
<td>1</td>
</tr>
<tr>
<td>300–1000 m</td>
<td>80</td>
<td>4.0</td>
<td>1935</td>
<td>96.0</td>
<td>0.76</td>
<td>0.52–1.11</td>
</tr>
<tr>
<td>&gt;1000 m</td>
<td>27</td>
<td>6.1</td>
<td>418</td>
<td>93.9</td>
<td>1.19</td>
<td>0.72–1.99</td>
</tr>
<tr>
<td>Continuous variable (per 100 m increase)</td>
<td>1.01</td>
<td>0.97–1.05</td>
<td>1.01</td>
<td>0.97–1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLBW</td>
<td>&lt;300 m</td>
<td>16</td>
<td>1.90</td>
<td>816</td>
<td>98.1</td>
<td>1</td>
</tr>
<tr>
<td>300–1000 m</td>
<td>27</td>
<td>1.3</td>
<td>1988</td>
<td>98.7</td>
<td>0.69</td>
<td>0.37–1.29</td>
</tr>
<tr>
<td>&gt;1000 m</td>
<td>8</td>
<td>1.8</td>
<td>4376</td>
<td>98.2</td>
<td>0.93</td>
<td>0.40–2.20</td>
</tr>
<tr>
<td>Continuous variable (per 100 m increase)</td>
<td>0.98</td>
<td>0.91–1.05</td>
<td>0.98</td>
<td>0.91–1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PB</td>
<td>&lt;300 m</td>
<td>42</td>
<td>5.0</td>
<td>790</td>
<td>95.0</td>
<td>1</td>
</tr>
<tr>
<td>300–1000 m</td>
<td>106</td>
<td>5.3</td>
<td>1909</td>
<td>94.7</td>
<td>1.04</td>
<td>0.72–1.51</td>
</tr>
<tr>
<td>&gt;1000 m</td>
<td>39</td>
<td>8.8</td>
<td>406</td>
<td>91.2</td>
<td>1.81</td>
<td>1.15–2.84</td>
</tr>
<tr>
<td>Continuous variable (per 100 m increase)</td>
<td>1.03</td>
<td>1.00–1.07</td>
<td>1.03</td>
<td>1.00–1.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGA</td>
<td>&lt;300 m</td>
<td>73</td>
<td>8.8</td>
<td>759</td>
<td>91.2</td>
<td>1</td>
</tr>
<tr>
<td>300–1000 m</td>
<td>160</td>
<td>7.9</td>
<td>1855</td>
<td>92.1</td>
<td>0.99</td>
<td>0.67–1.20</td>
</tr>
<tr>
<td>&gt;1000 m</td>
<td>36</td>
<td>8.1</td>
<td>409</td>
<td>91.9</td>
<td>0.92</td>
<td>0.60–1.39</td>
</tr>
<tr>
<td>Continuous variable (per 100 m increase)</td>
<td>1.00</td>
<td>0.97–1.03</td>
<td>1.00</td>
<td>0.97–1.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. LBW adjusted for: family status, education, maternal and paternal smoking, blood pressure, infant sex, parity, chronic diseases, previous preterm birth, and body mass index. TLBW adjusted for: family status, education, maternal smoking, alcohol consumption, blood pressure, infant sex, parity, previous preterm birth, and body mass index. PB adjusted for: family status, education, maternal and paternal smoking, parity, previous preterm birth, and maternal stress. SGA adjusted for: age, family status, education, maternal smoking status, maternal smoking, parity, previous preterm birth, and body mass index.

* p < 0.05.

Please cite this article in press as: Grazuleviene, R., et al. Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study. Int. J. Hyg. Environ. Health (2015), http://dx.doi.org/10.1016/j.ijihg.2015.02.004
Table 4
The effect of surrounding greenness on birth outcomes according to different NDVI sizes terciles (3rd tercile = highest greenness level).

<table>
<thead>
<tr>
<th>NDVI categories</th>
<th>NDVI-100</th>
<th>NDVI-300</th>
<th>NDVI-500</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LBW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd tercile</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd tercile</td>
<td>0.80 (0.76–1.74)</td>
<td>1.08 (0.71–1.65)</td>
<td>1.46 (0.95–2.23)</td>
</tr>
<tr>
<td>1st tercile</td>
<td>1.05 (0.76–1.46)</td>
<td>1.17 (0.77–1.78)</td>
<td>1.42 (0.92–2.20)</td>
</tr>
<tr>
<td>Continuous variable†</td>
<td>0.97 (0.77–1.21)</td>
<td>0.97 (0.80–1.17)</td>
<td>0.97 (0.80–1.17)</td>
</tr>
<tr>
<td><strong>TBW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd tercile</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd tercile</td>
<td>1.17 (0.58–2.34)</td>
<td>1.30 (0.62–2.73)</td>
<td>1.34 (0.61–2.96)</td>
</tr>
<tr>
<td>1st tercile</td>
<td>1.09 (0.53–2.23)</td>
<td>1.65 (0.80–3.37)</td>
<td>2.37 (1.14–4.95)</td>
</tr>
<tr>
<td>Continuous variable†</td>
<td>0.93 (0.64–1.35)</td>
<td>0.94 (0.69–1.29)</td>
<td>0.94 (0.69–0.97)</td>
</tr>
<tr>
<td><strong>PB</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd tercile</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd tercile</td>
<td>0.80 (0.56–1.16)</td>
<td>1.04 (0.73–1.49)</td>
<td>1.27 (0.90–1.81)</td>
</tr>
<tr>
<td>1st tercile</td>
<td>0.96 (0.66–1.38)</td>
<td>0.80 (0.55–1.17)</td>
<td>0.82 (0.55–1.22)</td>
</tr>
<tr>
<td>Continuous variable†</td>
<td>1.07 (0.87–1.31)</td>
<td>1.06 (0.89–1.25)</td>
<td>1.06 (0.89–1.25)</td>
</tr>
<tr>
<td><strong>SGA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd tercile</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd tercile</td>
<td>0.94 (0.68–1.29)</td>
<td>1.04 (0.76–1.42)</td>
<td>1.16 (0.84–1.59)</td>
</tr>
<tr>
<td>1st tercile</td>
<td>1.25 (0.91–1.72)</td>
<td>1.07 (0.78–1.41)</td>
<td>1.19 (0.87–1.65)</td>
</tr>
<tr>
<td>Continuous variable†</td>
<td>0.92 (0.78–1.09)</td>
<td>0.93 (0.81–1.08)</td>
<td>0.93 (0.81–1.07)</td>
</tr>
<tr>
<td><strong>Birth weight</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd tercile</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd tercile</td>
<td>16.1 (16.3–48.4)</td>
<td>10.9 (21.6–43.5)</td>
<td>2.32 (30.4–35.0)</td>
</tr>
<tr>
<td>1st tercile</td>
<td>−19.3 (−51.9–13.2)</td>
<td>−17.1 (−49.9–15.8)</td>
<td>−13.2 (−45.9–19.5)</td>
</tr>
<tr>
<td>Continuous variable†</td>
<td>13.2 (−3.7–30.2)</td>
<td>11.2 (−3.1–25.5)</td>
<td>10.9 (−3.1–25.1)</td>
</tr>
<tr>
<td><strong>Gestation age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd tercile</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2nd tercile</td>
<td>0.08 (−0.07–0.23)</td>
<td>0.03 (−0.12–0.18)</td>
<td>0.01 (−0.14–0.16)</td>
</tr>
<tr>
<td>1st tercile</td>
<td>0.02 (−0.14–0.17)</td>
<td>0.16 (−0.01–0.31)</td>
<td>0.12 (−0.14–0.16)</td>
</tr>
<tr>
<td>Continuous variable†</td>
<td>−0.03 (−0.11–0.05)</td>
<td>−0.07 (−0.14–0.01)</td>
<td>−0.07 (−0.15–0.01)</td>
</tr>
</tbody>
</table>

† LBW adjusted for: family status, education, maternal and paternal smoking, blood pressure, infant sex, parity, chronic diseases, previous preterm birth, and body mass index. PB adjusted for: family status, education, maternal and paternal smoking, parity, renal diseases, previous preterm birth, and maternal stress. BW adjusted for maternal and paternal height, maternal active smoking, marital status, infant sex, gestation duration, parity, BMI, previous preterm birth, maternal diabetes and chronic heath diseases. TLBW adjusted for: family status, education, maternal smoking, alcohol consumption, blood pressure, infant sex, parity, previous preterm birth and body mass index. SGA adjusted for: age, family status, education, maternal social status, maternal smoking, parity, previous preterm birth, and body mass index. Gestation age adjusted for: family status, education, maternal and paternal smoking, parity, renal diseases, previous preterm birth, and maternal stress.

Table 5
The effect of lower surrounding greenness (NDVI-500 < median) on the birth outcomes.

<table>
<thead>
<tr>
<th>Birth outcomes</th>
<th>Adjusted OR (95% CI)</th>
<th>p</th>
<th>Beta (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LBW</strong></td>
<td>1.15 (0.82–1.61)</td>
<td>0.419</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>TLBW</strong></td>
<td>1.92 (1.29–3.45)</td>
<td>0.032</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>PB</strong></td>
<td>0.81 (0.59–1.19)</td>
<td>0.159</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>SGA</strong></td>
<td>1.03 (0.79–1.33)</td>
<td>0.829</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>BW</strong></td>
<td>–</td>
<td>3.44 (−23.4–30.3)</td>
<td>0.757</td>
<td>–</td>
</tr>
<tr>
<td><strong>GA</strong></td>
<td>–</td>
<td>0.09 (−0.31–0.22)</td>
<td>0.115</td>
<td>–</td>
</tr>
</tbody>
</table>

Reference category NDVI-500 > median.

† LBW adjusted for: family status, education, maternal and paternal smoking, blood pressure, infant sex, parity, chronic diseases, previous preterm birth, and body mass index. TLBW adjusted for: family status, education, maternal smoking, alcohol consumption, blood pressure, infant sex, parity, previous preterm birth, and body mass index. PB adjusted for: family status, education, maternal and paternal smoking, parity, renal diseases, previous preterm birth, and maternal stress. SGA adjusted for: age, family status, education, maternal social status, maternal smoking, parity, previous preterm birth, and body mass index.

Adjusted regression coefficient.

reported that prenatal maternal stress is associated with pregnancy complications, poor foetal development and poor birth outcomes (Laurent et al., 2013). Prenatal maternal stress is associated with preterm birth and low birth weight (Hobel et al., 2008; Wainstock et al., 2014), and walking during pregnancy has a protective effect on low birth weight, preterm birth, and intrauterine growth restriction (Takito and Benicio, 2010) and also have a positive effect on stress reduction. Therefore for both exposures surrounding greenness and proximity to city parks, the biologic mechanisms of the green space effect on pregnancy outcomes could be similar.

Nevertheless with the high greenness values in the Kaunas (25th percentile of the NDVI-500 buffer was 0.498, and 75th was 0.587) study, we demonstrated an interaction between NDVI, residence distance to city parks and beneficial impacts on birth outcomes. The higher maternal physical activity during pregnancy, such as park use, might explain beneficial effect of greenness. The Kaunas residents’ random sample cohort study results showed that the proportion of park users is higher for those whose house is close to the park and park use decreases with increasing residence distance to green spaces (Tamosiunas et al., 2014). There were significant differences in the characteristics of the urban versus park environments in Kaunas, with higher levels of air pollution and noise compared with the park environment (Grazuleviciene et al., in press). In this study, significant higher levels of air PM2.5 and NO2 concentration, and noise level were found in the low greenness exposure area (NDVI < median) compared to the high greenness.

Please cite this article in press as: Grazuleviciene, R., et al., Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study. Int. J. Hyg. Environ. Health (2015), http://dx.doi.org/10.1016/j.ijheh.2015.02.004
Table 6
The effect of greenness covers (NDVI-500) and distance to city park on the risk of birth outcomes.

<table>
<thead>
<tr>
<th></th>
<th>Adjusted* OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LBW</strong></td>
<td></td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park ≤ 1000 m</td>
<td>1</td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park &gt; 1000 m</td>
<td>0.94 (0.48–1.83)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park ≤ 1000 m</td>
<td>1.01 (0.70–1.46)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park &gt; 1000 m</td>
<td>2.23 (1.20–4.15)</td>
</tr>
<tr>
<td><strong>PB</strong></td>
<td></td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park ≤ 1000 m</td>
<td>1</td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park &gt; 1000 m</td>
<td>1.77 (1.10–2.81)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park ≤ 1000 m</td>
<td>0.85 (0.61–1.19)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park &gt; 1000 m</td>
<td>1.40 (0.74–2.65)</td>
</tr>
<tr>
<td><strong>TLBW</strong></td>
<td></td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park ≤ 1000 m</td>
<td>1</td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park &gt; 1000 m</td>
<td>1.02 (0.29–3.61)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park ≤ 1000 m</td>
<td>1.73 (0.91–3.28)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park &gt; 1000 m</td>
<td>2.97 (1.04–8.45)</td>
</tr>
<tr>
<td><strong>SGA</strong></td>
<td></td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park ≤ 1000 m</td>
<td>1</td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park &gt; 1000 m</td>
<td>1.20 (0.75–1.92)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park ≤ 1000 m</td>
<td>1.04 (0.79–1.37)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park &gt; 1000 m</td>
<td>0.93 (0.49–1.74)</td>
</tr>
<tr>
<td><strong>Birth weight</strong></td>
<td></td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park ≤ 1000 m</td>
<td>1</td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park &gt; 1000 m</td>
<td>–1.36 (–50.7–48.0)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park ≤ 1000 m</td>
<td>2.34 (–26.2–30.9)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park &gt; 1000 m</td>
<td>–12.26 (–76.3–51.8)</td>
</tr>
<tr>
<td><strong>Gestation age</strong></td>
<td></td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park ≤ 1000 m</td>
<td>1</td>
</tr>
<tr>
<td>NDVI-500 &gt; median and distance to city park &gt; 1000 m</td>
<td>–0.14 (–0.37–0.09)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park ≤ 1000 m</td>
<td>0.12 (–0.01–0.25)</td>
</tr>
<tr>
<td>NDVI-500 ≤ median and distance to city park &gt; 1000 m</td>
<td>–0.18 (–0.48–0.12)</td>
</tr>
</tbody>
</table>

* LBW adjusted for: family status, education, maternal and paternal smoking, blood pressure, infant sex, parity, maternal and paternal smoking, blood pressure, infant sex, parity, chronic diseases, previous preterm birth, and body mass index. PB adjusted for: family status, education, maternal and paternal smoking, parity, renal diseases, previous preterm birth, and maternal stress. BW adjusted for: maternal and paternal height, maternal active smoking, marital status, infant sex, gestation duration, parity, BMI, previous preterm birth, maternal diabetes and chronic heart diseases. TLBW adjusted for: family status, education, maternal smoking, alcohol consumption, blood pressure, infant sex, parity, previous preterm birth, and body mass index. SGA adjusted for: age, family status, education, maternal and paternal smoking, parity, previous preterm birth, and body mass index. Gestation age adjusted for: family status, education, maternal and paternal smoking, parity, renal diseases, previous preterm birth, and maternal stress. p < 0.05.

exposure area (NDVI > median). These differences in ambient air exposure, surrounding greenness level and park exposure may have an impact on psycho-physiological stress, homeostasis and hemodynamic parameters of mothers and through placental blood flow influence of foetal physiological well-being and foetal growth.

The current cohort study had the advantage of using a large number covariates gathered during interview, thus may individually control for covariates, associated to birth outcomes, such as migration, smoking, maternal diseases and others. However, there are exposure classification difficulties because of the limited ability to separate the greenness effect by NDVI and distance to city parks. Nevertheless both measures are objective and estimated at individual level. NDVI presents the level of surrounding greenness but does not distinguish between e.g. grass fields and trees. In the current study, we have no data for usage of green spaces during pregnancy and that may cause exposure classification errors, however, maternal exposure to greenness was based on the home address and this has improved exposure classification. A further limitation of this study was that personal activity patterns, such as time spent outdoors and time spent at work or home were not accounted for. However, this limitation in exposure estimation is assumed to be random. In this cohort study the lack of statistical significant associations between some adverse birth outcomes and greenness might be due to the small number of cases.

**Conclusion**

This study is one of the first to evaluate the modifying effect of surrounding greenness in the living environment and the distance to city parks for various birth outcomes and demonstrates associations between surrounding greenness, distance to city park and low birth weight, term low birth weight and preterm birth. The beneficial park effect on foetal growth is most apparent in the environment with low surrounding greenness. Greenness level has a stronger effect; therefore in the areas with low greenness level, the park proximity effect becomes more prominent. Although our findings of a modifying effect of surrounding greenness and distance to city parks requires further confirmation by other studies, they highlight the need for more research on the effect of the natural environment on reproductive health. The future studies should include surrounding greenness characteristics and data for usage of green spaces during pregnancy. This cohort study adds to the growing evidence that green space positively affects pregnancy outcomes.

**Conflict of interest statement**

Authors declare that they have no conflicts of interests to disclose.

**Acknowledgements**

This work was supported in part by the European Commission grant number FP6-036224; the original study on which the present article is based received grant number FP7-282996, and the grant of Lithuanian Agency for Science Innovation and Technology (MITA), number 2012-07-20 no. 31V-125.

**References**


