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Review

Association between residential greenness and birth weight: Systematic review and meta-analysis

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ABSTRACT

Birth weight is extensively investigated as an outcome of interacting with greenery in mothers' living environment, because it is one of the major causes for neonatal and infant mortality, as well as a correlate of some adverse effects in childhood and beyond. Conversely, in modern urban-ecological systems the access to greenery is limited. The aim of this study was to answer the question whether green spaces and generally greenery in the living environment of pregnant women are associated with the birth weight of their infants and what the direction of that effect is. MEDLINE, EMBASE and the Internet were searched for relevant publications in English and Spanish. Eight studies were identified and included in the analyses (total $n = 214\,940$). We report quality effects meta-analyses based on correlation and standardized regression coefficients as estimates of effect size. Neighbourhood greenness within 100-m buffer was weakly and positively associated with birth weight. The pooled correlation coefficient was 0.049 (95% CI: 0.039, 0.059) and the pooled standardized regression coefficient was 0.001 (95% CI: −0.001, 0.003). There was, however, considerable heterogeneity between the studies. Using more sensitive measures for greenness and taking into account green space functionality and quality, adjusting for environmental exposures, and assessing individual attitudes towards nature, might yield clearer picture, higher statistical power and more precise results in future research. Our findings endorse the emphasis put on urban forestry and landscape management as closely related to public health and propose a more naturalistic, humanitarian and person-centered approach in future studies.

Introduction

In the past decades considerable body of evidence regarding the benefits from urban greenery has accumulated. Only in the past few years, however, the public health community started to take a closer look at the associations between residential greenery and foetal development (Agay-Shay et al., 2014; Hystad et al., 2014; Dadvand et al., 2012a,b, 2014; Donovan et al., 2011; Markevych et al., 2014; Laurent et al., 2013). Specifically, birth weight is extensively investigated as an outcome of interacting with greenery in mothers' living environment, because low birth weight is one of the major causes for neonatal and infant mortality (Mathews and MacDorman, 2010; Hack et al., 1995), as well as a correlate of some adverse effects in childhood and beyond (Miles et al., 2005). Conversely, in modern urban-ecological systems the access to municipal parks is limited (Barbosa et al., 2007). Robust scientific evidence has emphasized the critical need of green spaces within cities to ameliorate various problems of city-living (Singh et al., 2010).

Kihal-Talantikite et al. (2013) presented in-depth overview of the pathways that are hypothesized to mediate the effects of greenness on pregnancy. Green vegetation might influence pregnancy via psychological, physiological and environmental pathways, which are likely interrelated. Greenery is associated with wellness in general (Brymer et al., 2010). It can also reduce stress (Ward Thompson et al., 2012) and noise annoyance (Dzhambov and Dimitrova, 2014). By reducing maternal stress, noise annoyance and catecholamine concentrations vegetation might positively affect foetal development via improved oxygenation, nutrition and metabolism. A recent meta-analysis by Bowler et al. (2010) found positive effect of green natural environments in comparison to build environments in reference to anger, mental fatigue, depression, energy and attention.

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Interacting with nature encourages health-enhancing behaviours such as green exercise and social contacts (Roe and Aspinall, 2011; Barton and Pretty, 2010). In regards to psychological health, even a brief time spent in green spaces or looking at them through a window are considered to be "micro restorative episodes" (Kaplan, 2001; Velarde et al., 2007). Green space interaction can promote stress reduction and assist in mental recovery following intensive cognitive activities (Depledge et al., 2011). A larger acreage of urban green spaces were linked to fewer depressive symptoms (Miles et al., 2012), and lower odds of obesity among adults of all ages (Pereira et al., 2013).

Finally, tree canopies and vegetation biomass can regulate neighbourhood microclimate by reducing particle matter and air pollution (Akbari, 2002; Dadvand et al., 2012c), ameliorating heat waves (Susca et al., 2011), moisturising the air and blocking sound waves (Van Renterghem et al., 2012; Land Use Consultants, 2004).

The combined benefits of residential vegetation are most likely to result in positive neuroendocrine and consecutively placental response in the maternal organism. However, to this moment there is no synthetic research on the effects of urban greenery on birth outcomes. As this is a new field in environmental epidemiology and medical geography we believe that it is time to broaden the theoretical and methodological framework for future research. Therefore the aim of this review was to answer the question whether green spaces and generally greenery in the living environment of pregnant women are associated with the birth weight of their infants and what the direction of that effect is, and to propose some new methodological approaches.

Material and methods

Search protocol

The first step was to search the Internet (Google) as well as relevant databases in order to identify different mechanisms linking residential greenness to birth weight. Then we checked MEDLINE, EMBASE, Internet and PROSPERO (http://www.crd.york.ac.uk/PROSPERO/) for previous systematic reviews on this topic and none were found.

Two experts carried out the review process. A detailed research protocol and standard data extraction forms were developed a priori for the reviewers after they were presented with the research question. Databases of published peer-reviewed literature – MEDLINE (PubMed), EMBASE (ScienceDirect) – and the Internet (Google) were searched for relevant publications in English and Spanish through January 21, 2014 in order to ensure comprehensive coverage of the literature. (Overlapping papers were considered only once, but they are included in the overall results reported for each data source.) We used the following free-text term keyword combinations: "greenery + birth", "greenery + pregnancy", "green spaces + birth", "green spaces + pregnancy", "vegetation + pregnancy", "vegetation + birth", "trees + pregnancy", "trees + birth", "vegetation + birth outcomes", "espacio verde + embarazo", "espacio verde + peso al nacer".

Additionally Health Technology Assessments database was searched to identify grey literature and Bulgarian experts in environmental medicine, social medicine and obstetrics were contacted to obtain unpublished data and grey literature. Some authors were contacted as well (P. Dadvand, K. Agay-Shay). Reference lists of included studies were hand-searched, but no information was retrieved. During the peer-review of this paper, three additional studies were published (Dadvand et al., 2014; Agay-Shay et al., 2014; Hystad et al., 2014), therefore they were included when submitting the revised version as well. Fig. 1 presents a flow diagram of the review process.

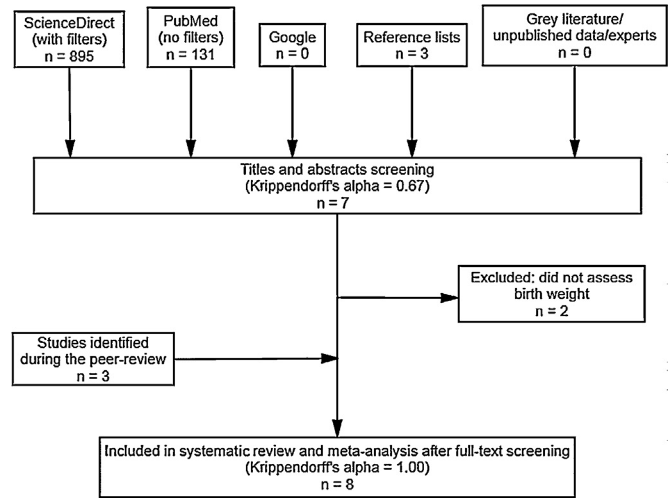

Fig. 1. Flow diagram of study selection and screening process.

Observational and epidemiological studies examining the relationship between residential green spaces, vegetation or greenness and birth outcomes of local women were included. Studies were screened on three levels: titles, abstracts and full texts. Screening was conducted by two reviewers working independently and any disagreements were resolved through consensus with a third reviewer. Krippendorff's alpha coefficient was used to determine the degree of inter-rater agreement (Hayes and Krippendorff, 2007). Eight studies were finally included in the meta-analysis.

Quality assessment

Individual study quality assessment methodology was adapted from Croteau (2009) and Doi and Thalib (2008). The checklist assigned a maximum of 1.00 point for different methodological elements and a unit-weighted quality score (summary score for all elements/12) was then calculated (see Appendix A). Quality scores were classified as follows: 1.00–0.80 (high quality), 0.79–0.60 (moderate quality) and <0.60 (low quality). Inter-rater agreement regarding the quality scores was above 0.90 (Table 1).

Meta-analytical strategy and analyses

Meta-analysis was performed to estimate the effects of neighbourhood greenness on birth weight. Each study was a unit of analysis. We extracted effect size estimates for models including the study population disregarding any subgroup stratification (unless the predictor or outcome variables were present only in that subgroup). From each study we extracted the effect size adjusted for most of the personal covariates and for NO/NO_2, noise or walkability as environmental confounders, when they were reported by the authors. For the study of Laurent et al. (2013) we included the regression coefficient associated with the model adjusted for NO_x estimated via CALINE4 dispersion model rather than the model controlling for nitric oxides recorded by monitoring stations. For Dadvand et al. (2012b) we used the effect size reported for 2007, because it adjusted for NO_2 in contrast to that for 2003. For Markevych et al. (2014) we looked at the model adjusting for NO_2 rather than the one controlling for noise exposure, because the latter referred only to Munich. All main associations between greenness and birth weight were analysed within a 100-m buffer (or the closest to it), because it allowed comparability between studies. We did not calculate point estimates for educational subgroups. Supplementary materials provide additional data and calculations for a 250-m buffer. When proximity to green

Table 1
Characteristics of the included studies and scores for each quality element.

Study	Donovan et al. (2011)	Dadvand et al. (2012b)	Dadvand et al. (2012a)	Laurent et al. (2013)	Markevych et al. (2014)	Agay-Shay et al. (2014)	Dadvand et al. (2014)	Hystad et al. (2014)
Sample size	5 295 (1)	2 393 (1)	8 246 (1)	81 186 (1)	3 203 (1)	39 132 (1)	10 780 (1)	64 705 (1)
Design[4]	Cross-sectional (0.25)	Cross-sectional (0.25)	Cross-sectional (0.25)	Cross-sectional (0.25)	Cross-sectional (0.25)	Cross-sectional (0.25)	Cross-sectional (0.25)	Cross-sectional (0.25)
Country	USA (1)	Spain (1)	Spain (1)	USA (1)	Germany (1)	Israel (1)	England (1)	Canada (1)
Timeframe	2006-2007 (1)	2003-2008 (1)	2001-2005 (1)	1997-2006 (1)	1996-1999 (1)	2000-2006 (1)	2007-2010 (1)	1999-2002 (1)
Response rate	All singleton live births in single-family homes (1)	45% in Asturias, 68% Gipuzkoa, 60% in Sabadell and 54% in Valencia, mean = 56.75% (0.5)[1]	All singleton live births in Barcelona (1)	93% successfully geocoded mothers (1)	55% for LISAplus study and ≈ 65.5% for GINIplus study (0.75)[3]	99.9% of all births in Israel (1)	54% of all births (0.5)	All births (1)
Definition of birth weight	Small for gestational age (0.25)	Birth weight in grams (1)	Birth weight in grams (1)	Birth weight in grams (1)	Birth weight in grams (1)	Birth weight in grams (1)	Birth weight in grams (1)	Birth weight in grams (1)
Assessment of birth weight	Birth certificates (1)	Clinical examinations (1)	Official database, clinical examinations (1)	Neonatal records from perinatal research database (1)	Clinical examination (1)	Official database (1)	Bradford Royal Infirmary registry (1)	Vital statistics birth records (1)
Assessment of residential greenery	Classified aerial imagery (0.75)	NDVI (0.75)	NDVI (0.75)	NDVI (0.75)	NDVI (0.75)	NDVI (0.75)	NDVI (0.75)	NDVI (0.75)
Plausibility	Plausible (0.75)	Plausible (0.75)	Plausible (0.75)	Plausible (0.75)	Plausible (0.75)	Plausible (0.75)	Plausible (0.75)	Plausible (0.75)
Adjustments for personal covariates	Age, obstetric history, socio-economic class (0.1)	Maternal age, socio-economic status, BMI, smoking, alcohol, obstetric history (0.75)	Socio-economic status, maternal age, smoking, alcohol, obstetric history, chronic diseases, maternal body weight (1)	Maternal age, socio-economic status, obstetric history, chronic diseases (0.1)	Maternal age, smoking (0.5)	Maternal age, socio-economic status (0.1)	Maternal age, BMI, smoking, alcohol, parity (0.75)	Maternal age, parity, smoking, socio-economic status (0.75)
Adjustments for environmental covariates	None (0)	NO_2 (0.5)	Distance to major roads[2] (0.75)	NO_x (0.5)	NO_2 (0.5)	PM_{10} (0.5)	Environmental tobacco smoke (0.5)	Air pollution, noise, walkability (1)
Effect size calculation for meta-analysis[5]	OR → r (0.75)	B → β → r (0.5)	B → β → r (0.5)	B → β → r; SD of mean birth weight is imputed (0.25)	B → β → r (0.5)	B → β → r (0.5)	B → β → r (0.5)	B → β → r (0.5)
Overall quality score	0.65 (moderate)	0.75 (moderate)	0.83 (high)	0.72 (moderate)	0.75 (moderate)	0.74 (moderate)	0.75 (moderate)	0.83 (high)

Note. In brackets – quality score for each element; OR – odds ratio; *r* – correlation coefficient; NDVI – Normalized Difference Vegetation Index; *B* – unstandardized regression coefficient; *β* – standardized regression coefficient; SD – standard deviation.

[1] Information extracted from Guxens et al. (2012).

[2] Score reduced to 0.75 because the distance is only a proxy for air and noise pollutions.

[3] Information extracted from Heinrich et al. (2002) and von Berg et al. (2013).

[4] Refers specifically to the association greenness–birth weight[5] With *r* as effect size estimate.

spaces or neighbourhood greenness were reported in some studies as proxies for greenness, we did not consider the effect sizes associated with them to ensure maximum comparability between studies (Dadvand et al., 2012a; Markevych et al., 2014; Agay-Shay et al., 2014).

Two types of effect size estimates are reported. The main meta-analysis was based on correlation coefficients (r) as a well-known effect size estimate, and the secondary analysis reported pooled standardized regression coefficients (β). Majority of the studies used multivariate linear regression to determine the effect of residential greenery on birth weight, so we converted the unstandardized regression coefficients to r with series of transformations. When necessary, the direction of the effect was reversed (Donovan et al., 2011). Additional data imputation was applied when needed. Detailed description of the computations is presented in Appendix B and basic input data is available in Supplementary materials. The meta-analyses were conducted with MetaXL v. 2 for MS Excel v. 2010 (http://www.epigear.com/).

Correlation coefficients were entered along with the corresponding standard errors (Effect size entry: ContSE; method: QE) and the software was set to produce pooled r with 95% CI. Standardized regression coefficients were inputted (Effect size entry: ContSE; method: QE) along with the corresponding standard errors. These two estimates were chosen because, on one hand, recently Nieminen et al. (2013) summarized procedures for using β as effect size indices and illustrated them in a meta-analysis on the relationship between polychlorinated biphenyls and birth weight, which deems their approach highly relevant to our research. On the other hand, however, β are relatively unknown in study synthesis and raise some concerns (e.g. different control variables across the studies, multicollinearity, insufficiently reported data to compute standardized regression coefficients and/or their standard errors) (Kim, 2011).

Data entry to create the dataset was carried out independently by two reviewers to avoid typing errors (Krippendorff's alpha for the two meta-analyses using r and β was >0.95) (See Supplementary materials for input data of individual studies and effect sizes for the 100-m and 250-m buffers). Quality effects meta-analytical model was applied (Doi and Thalib, 2008, 2009) because if the studies included in the meta-analysis differ in a systematic way from the possible range in the population, they are not representative of it and the random effects model does not apply (Overton, 1998). The quality effects model uses a quality index Qi (0.00–1.00) (derived from the overall quality scores in Table 1) representing higher probability the study is credible as it approaches the value of 1.00. Quality indices for the 100-m buffer analyses were calculated by assigning Qi of 1.00 to Dadvand et al. (2012a) and Hystad et al. (2014) as the "best" studies according to the list of predefined safeguards against bias (see Table 1) and then dividing the score of each of the other studies by the score of Dadvand et al. (2012a)/Hystad et al. (2014) (Barendregt and Doi, 2014). From Qi a study specific composite was generated that took into consideration study specific information and its relationship to other studies to re-distribute inverse variance weights. According to Doi (2014), the quality effects model should replace the currently used random effects model as it always outperforms it.

The pooled effect size for r was classified as small (≤0.10), medium (0.10–0.39) and large (≥40) (Cohen, 1998 cited by Gonzalez et al., 2008). Results were considered statistically significant at $P < 0.05$. Heterogeneity was explored using the chi-square test. The quantity of heterogeneity across studies was measured by the I^2 statistic (Higgins et al., 2003). According to I^2 values, heterogeneity was considered mild (<30%), moderate (31–50%) and high (>50%) (Higgins and Thompson, 2002). Sensitivity analysis was performed by assessing the contribution of individual studies to the summary effect estimate by excluding each study, one at a time, and computing meta-analysis estimates for the remaining studies. With only eight studies the power of testing for publication bias might be too low to distinguish chance from real asymmetry (Sterne et al., 2011), therefore funnel plot and Egger's regression analysis were omitted.

Results

Description of the studies

Eight studies on the research topic were identified. They were published in the recent years (2011–2014) which reiterates the growing interest towards urban forestry and planning in public health research. The eight datasets contained a total of 214 940 cases of pregnant women. Samples varied considerably from a couple of thousand to over eighty thousand and they were all drawn from cohort studies (or retrospectively from official obstetric databases). The study of Laurent et al. (2013) was distinguished by the largest sample and nearly one decade of data accumulation. All studies were conducted in developed countries with relatively high social standard. Some studies were carried out in Europe (Markevych et al., 2014; Dadvand et al., 2012a,b; Dadvand et al., 2014), while others were carried out in North America (Laurent et al., 2013; Donovan et al., 2011; Hystad et al., 2014) or Asia (Agay-Shay et al., 2014).

Generally, all studies had somewhat similar methodology. They used official birth records and in some cases prospectively contacted the mothers in person (Dadvand et al., 2012a,b; Markevych et al., 2014). Obstetric and personal data were then geocoded to determine the effect of residential greenness on birth weight at different radii around mother's home address. Seven out of eight studies used the Normalized Difference Vegetation Index (NDVI) as a proxy for environmental greenness (Agay-Shay et al., 2014; Hystad et al., 2014; Dadvand et al., 2014; Dadvand et al., 2012a,b; Markevych et al., 2014; Laurent et al., 2013), while Donovan et al. (2011) used classified aerial imagery to focus specifically on tree canopies. In fact, the latter study differed on the definition of birth weight as well. While the others defined the outcome measure as birth weight in absolute units (g) and used it as input for correlation-based analyses, Donovan et al. (2011) examined a dichotomized variable representing small for gestational age which was then analysed with logistic regression.

All studies adjusted their regression models for personal confounders, however only some of them were deemed relevant to birth weight according to the protocol of Croteau (2009). Donovan et al.'s (2011) study was the only one not adjusting for environmental pollutants, and only Hystad et al. (2014) adjusted their regression model for neighbourhood walkability.

With the exception of Dadvand et al. (2012a), all studies found positive association between residential greenness and birth weight at ≈100-m buffer, and all four studies (Dadvand et al., 2014; Dadvand et al., 2012b; Markevych et al., 2014; Agay-Shay et al., 2014) reported positive effect at 250-m buffer (See Supplementary materials). In order to determine the pooled association we performed meta-analyses.

Data synthesis (100-m buffer) – Correlation coefficients

We detected considerable inter-study heterogeneity ($I^2 = 99.70$). Table 2 reports individual and pooled effect sizes as well as heterogeneity statistics. Fig. 2 depicts a forest plot. Generally, neighbourhood greenness within 100-m buffer was weakly but significantly and positively associated with birth weight. Sensitivity analysis revealed that by excluding each study one at a time pooled r remained small (0.048–0.050) and significant. Heterogeneity did not change and remained high.

Table 2
Meta-analysis results for 100-m buffer (correlation coefficients, quality effects model).

Study	*r*	LCI	UCI	Weight (%)
Dadvand et al. (2014)	0.054	0.050	0.057	1.768
Dadvand et al. (2012a)	−0.001	−0.004	0.001	2.373
Dadvand et al. (2012b)	0.057	0.051	0.063	1.496
Markevych et al. (2014)	0.054	0.049	0.058	1.952
Laurent et al. (2013)	0.050	0.050	0.051	58.641
Donovan et al. (2011)	0.004	0.0003	0.007	1.511
Agay-Shay et al. (2014)	0.052	0.051	0.052	16.849
Hystad et al. (2014)	0.053	0.053	0.054	15.770
Pooled *r*	0.049	0.039	0.059	100.000
Heterogeneity statistics				
I^2	99.697	99.639	99.746	
Cochran's *Q*	2313.422			
χ^2, *P*	<0.001			
Q-Index	10.829			

Note. LCI – Lower 95% CI; UCI – Upper 95% CI; *r* – correlation coefficient.

Table 3
Meta-analysis results for 100-m buffer (standardized regression coefficients, quality effects model).

Study	β	LCI	UCI	Weight (%)
Dadvand et al. (2014)	0.004	0.0003	0.007	1.766
Dadvand et al. (2012a)	−0.001	−0.004	0.002	2.372
Dadvand et al. (2012b)	0.007	0.001	0.013	1.494
Markevych et al. (2014)	0.004	−0.001	0.008	1.591
Laurent et al. (2013)	0.0004	0.0001	0.001	58.728
Donovan et al. (2011)	0.005	0.0003	0.010	1.887
Agay-Shay et al. (2014)	0.002	0.001	0.002	16.872
Hystad et al. (2014)	0.003	0.003	0.004	15.790
Pooled β	0.001	−0.001	0.003	100.000
Heterogeneity statistics				
I^2	91.051	84.775	94.740	
Cochran's *Q*	78.221			
χ^2, *P*	0.0001			
Q-Index	10.812			

Note. LCI – Lower 95% CI; UCI – Upper 95% CI; β – standardized regression coefficient.

Alternative approach (100-m buffer) – Standardized regression coefficients

Heterogeneity was high (I^2 = 91.05) and under the quality effects model the meta-analysis produced marginally significant pooled regression slope of 0.001 (95% CI: −0.001, 0.003) (see Table 3 and Fig. 3). Sensitivity analysis did not reveal considerable changes.

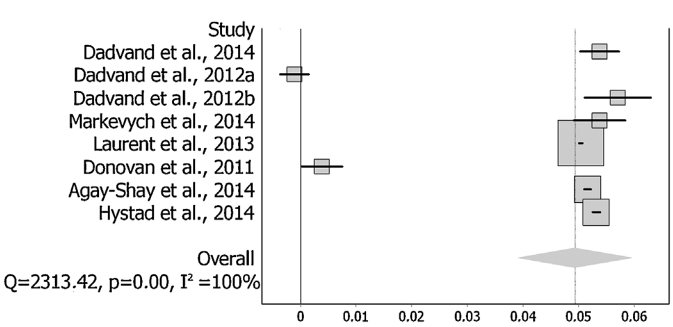

Fig. 2. Forest plot on the effect of residential greenness on birth weight (correlation coefficients, quality effects model).
Note. ES – effect size; *Q* and I^2 – heterogeneity statistics.

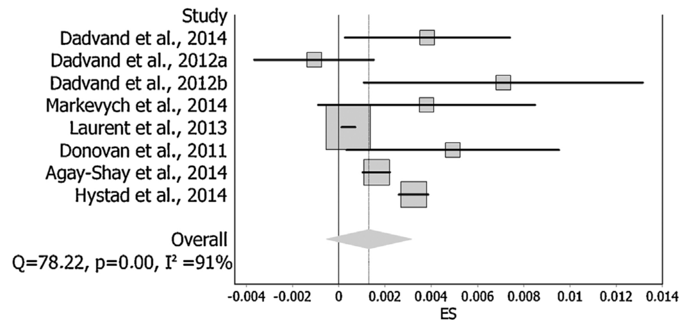

Fig. 3. Forest plot on the effect of residential greenness on birth weight (standardized regression coefficients, quality effects model).
Note. ES – effect size; *Q* and I^2 – heterogeneity statistics.

Conversely, under the random-effects model the slope was statistically significant – β = 0.002 (95% CI: 0.001, 0.003).

Discussion

Principal findings

We performed meta-analyses on eight published studies exploring the association of residential greenness and birth weight. Our main analyses focused on greenness in 100-m radius or less around mothers' home address, disregarding further stratification by educational attainment. It was found that under the quality effects model there was a weak positive and significant association between greenness and birth weight based on pooled correlation coefficients and marginally significant association based on the pooled regression slope. This was the conclusion of all studies but one (Dadvand et al., 2012a) which found significant association only among the lowest educational group. It has been hypothesised that people with lower education might be benefiting more from neighbourhood greenery because they spend more time at home and have increased opportunities to interact and benefit from it. Markevych et al. (2014) and Dadvand et al. (2012b) also found the highest positive effect among women with lower education. As for the buffer around mothers' home, we limited our main analysis to the buffer that allowed comparison across studies (i.e. ≈100-m). However, Supplementary materials report pooled results for 250-m, which still allow drawing some inferences although based on fewer studies. According to some studies evaluating the effect at wider radii, a 500-m buffer was associated with the highest regression coefficients (Dadvand et al., 2012b; Markevych et al., 2014). Dadvand et al. (2012a) reported increase of 436.3 g (95% CI: 43.1, 829.5) per 10% increase in NDVI within 100-m buffer among the lowest education level group, while in the study of Dadvand et al. (2012b), the increase was 63.3 g (95% CI: 1.7, 124.9) for women with primary of without education for one IQR increase in average NDVI within 500-m buffer. According to Markevych et al. (2014), within 500-m buffer the birth weight was increasing with 58.2 g (95% CI: 2.0, 114.4) when the mother had low education level. In Dadvand et al. (2012b), there was increase in birth weight of 34.4 g (95% CI: 1.9, 67.0) for one IQR increase in NDVI within a 500-m buffer, without any stratification by educational attainment. The fact that wider buffers were associated with stronger effects suggests that the social function of urban green spaces rather than visual stress attenuation might be driving these effects.

Finally, although some studies reported associations with other birth outcomes such as preeclampsia, preterm delivery and head circumference (Hystad et al., 2014; Dadvand et al., 2012a,b; Laurent et al., 2013; Agay-Shay et al., 2014), they were not included as outcome measures in our analysis because they could not be synthetized across all studies.

Quality of evidence and future research

Overall, the eight studies were similar in quality and design. The positive effect of greenness on birth weight was endorsed by six studies of moderate quality and one of high quality as opposed to one high quality study pointing towards positive effect only amid poorly educated women. The low response rate of some (Dadvand et al., 2012b, 2014; Markevych et al., 2014) should not be particularly troublesome, because their sample sizes seemed sufficient and by combining official records, GIS analysis and self-report data they were able to control for many of the relevant confounders related to both the environment and the mother herself. Referring to the former, some studies ignore noise pollution or use surrogates for it (Dadvand et al., 2012a). The recent systematic review by Hohmann et al. (2013) is sometimes cited as evidence for lack of effect of noise on birth outcomes. However, a relatively unknown meta-analysis made for the government of Quebec (Croteau, 2009) found that noise exposure ≥85 dB during pregnancy results in significantly higher odds for small for gestational age. Ristovska et al. (2014) also found evidence for negative effects of noise on birth weight. Therefore, environmental and occupation noise should be given full consideration in future research along with air pollution indicators.

Another limitation of all studies to this moment are the indicators they chose as a proxy for residential greenness. NDVI and the tree canopy index may lead to considerable imprecision due to the resolution of analysis which performs poorly when the buffer is small and greenness patterns are irregular (Laurent et al., 2013); likewise, NDVI carries no information about the type and use of the vegetation (Richardson et al., 2012). Although the studies include thousands of individual cases and thus the mentioned above green space measures are relatively easy to apply when the address of the mother is geocoded, future research will have to find a way to measure the type of greenery (street vegetation, urban parks, private gardens, green roof installations, etc.), because many of those are either restricted to some citizens, are not visible or do not possess restorative and aesthetic properties needed to engage people in social and physical activities or to reduce their stress levels. Urban forests and spaciously deep natural landscapes might have different potential to benefit humans. Local green space quality should also be taken into consideration since quality and specific characteristics of public parks such as attractiveness influence individual health. Parks with more attractive and aesthetically pleasing features are associated with higher rates of use for recreation and physical activity (Evenson et al., 2006; Giles-Corti et al., 2005; Kaczynski et al., 2008; Kaczynski, 2010; Parra et al., 2011), which are possibly the key paths mediating the positive effect of greenery on foetal development. Public health field might have to adopt some instruments from environmental psychology to measure individual connectedness to nature, which might be moderating or mediating the effect of nature on human emotional response and behaviour in natural settings (Howell et al., 2011; Mayer et al., 2009). The "perceived benefits of nature" construct is also hypothesized to explain some of the individual differences in the reactions to nature (Dzhambov, 2014).

Currently adopted approaches to assess the relationship of greenery with birth weight and foetal development in general might be considered a form of reductionism, oversimplifying the interaction with urban greenery and reducing it to a form of "exposure". Richardson considered it "appropriate to refer to green space exposure" and compared it to exposure to air pollutants (Richardson, 2014). The argument was that, from environmental medicine perspective, it is a positive approach to broaden the "traditional narrower concept of exposure" (Richardson, 2014). Hystad et al. (2014) went even further and reported exposure-response relationships between greenness and birth outcomes. Such "exposure-response" approach towards urban greenness is an oversimplification from the point of view of all fields dedicated to more or less humanitarian methods of research. Despite of founding their theory on various behavioural, psycho-emotional and social mechanisms which probably mediate the effects of greenness on pregnancy, the authors fail to control for these pathways and to conceptualize birth outcomes in their framework. We believe that the need for more theory-driven studies is growing. Urban green spaces need not be treated as mechanical systems, but rather as socially contextualized and having phenomenological meaning attached to them. By focusing prospectively on a smaller population of pregnant women, rather than extracting data from massive official records and linking it to individual characteristics and geomorphological variables, future research might capture the wider panorama of both observed and unobserved phenomena which constitute the structure of the bio-socio-ecological functioning of man within urban nature.

Adopting some urban planning approaches might also benefit future research. Different street grids and geomorphological characteristics of cities might be accounting for much of the effect of greenness on birth weight. For example, if one of the key benefits of living in a greener environment is the opportunity to visit urban parks, where you could exercise, socialize, relax, etc., then it is very plausible that the street configuration surrounding those parks might be accounting for part of the effects. Hystad et al. (2014) were the only ones including neighbourhood walkability covariate in their analyses and this is really commendable. We suggest that implementing other approaches such as space syntax might help further adjust the models for urban fabric. Briefly, space syntax theory explores the inter-relations of space, movement at different scales and land use patterns, that is, the relationship between configuration of the road network and pedestrian flow (Hillier, 2007). It predicts human walking behaviour and navigation based on mathematical expressions of visibility from a certain location and the route choices that a person is most likely to make given the geometrical properties of the street network. Therefore, by linking the understanding of urban form and human spatial cognition, "green space and birth weight" studies might account for mothers' frequentation of urban greens spaces by exploring the integration of those green spaces in the local street grid.

Lastly, we speculate that the statistical processing of future studies might have to implement analyses and designs capable of establishing causality and the actual scientific importance of the revealed associations. Adding a dichotomised estimate of low birth weight (Donovan et al., 2011; Hystad et al., 2014; Agay-Shay et al., 2014) yields better interpretation of the results, since statistical significance not always corresponds to scientific importance. Furthermore, smaller scaled studies, which focus on individual differences in the responses to greenery as they relate to birth outcomes, might need more sophisticated procedures like structural equation modelling to operationalize the constructs underlying urban vegetation's effects. We also suggest using quality effects meta-analytical model in other meta-analyses, which has been discussed as superior alternative to the classical random effects model (Doi and Thalib, 2008, 2009) and which, as demonstrated by this study, produced marginally significant results for the pooled regression slope at 100-m as opposed to the random effects model.

Strengths and limitations

This was the first study to perform a systematic review or meta-analysis on the association between residential greenness and birth weight, which has been urgently debated and evaluated in the recent years. Our paper might serve as a starting point for future synthetic research. It was one of the few to have used the quality effects model which was indispensable given the high heterogeneity across the studies and the possible sources of bias.

Nevertheless, our study has several limitations. The most prominent is the small number of included studies. When there is little evidence, reporting meta-analysis of only eight studies or less is acceptable and is not a precedent (Croteau, 2009; Griffiths et al., 2005). Our choice to carry out quantitative analysis is indirectly supported by Davey et al. (2011) who reviewed 22 453 meta-analyses from Cochrane Database of Systematic Reviews and found that about 75% of the meta-analyses in each of the categories "gynaecology, pregnancy and birth", "obstetrics outcomes" and "continuous data type" contained no more than five studies.

Because most studies reported unstandardized regression coefficients, converting them to correlation coefficients required several transformations and in some occasions data imputation. Standardized beta-coefficients were also used as effect size estimates; however this is an unpopular approach which is not directly incorporated (i.e. generic effect size imputation is required) in most software packages and has its limitations (Kim, 2011; Nieminen et al., 2013). Another issue might be that for Donovan et al. (2011) the outcome measure was dichotomous rather than an interval variable, and therefore the actual association between tree canopy percentages in 50-m radius and birth weight in terms of actual weight in grams is probably stronger than the estimated based on the OR.

The quality criteria we employed are not well introduced in the literature; however they were developed on the basis of the expert and professional research of Croteau (2009) and modified for our specific purposes. It is always important to use study-specific quality assessment procedure. Regardless, the assessment of some components was somewhat arbitrary: for example, controlling for the distance to major roads was assigned a higher score than the adjustment for NO_2, because it is a proxy for both air and noise pollutions. On the other hand, due to the statistical approach and the attempt to extract effect size estimates related to the most comparable models, some viable information regarding the urban fabric and social determinants has been lost.

Nevertheless, the most important question was whether greenness had positive effect on birth weight and by confirming it this study reiterates the importance of green space management and planning for environmental medicine and public health. Because we were mainly concerned with the specificity of the point estimate our analysis is conservative, probably overly so. For mothers with low education 500-m buffer greenness might be associated with birth weight stronger than the estimated.

Conclusion

In the Modern World where more and more people are living in big cities it is important to consider social necessities in site selection and design for green spaces. The international standard suggested by World Health Organization is a minimum availability of 9 m^2 green open space per city dweller (Kuchelmeister, 1998), but often it cannot be met. It has been speculated that domestic gardens and green areas around living facilities could enhance the overall functional size of green space network by functioning as corridors and patches (Singh et al., 2010). If adequate actions are not taken by local authorities and public health experts, the access to green spaces could decline rapidly, thus increasing the geographical isolation of people from nature (Fuller and Gaston, 2009). Our findings endorse the emphasis put on urban forestry and landscape management as closely related to public health and reiterate the transdisciplinary approach that needs to be undertaken. This paper is a timely reminder that a more naturalistic, humanitarian and person-centered approach is warranted when the research focuses on human–nature relationships.

This meta-analysis showed that residential greenness within approximately 100-m buffer is positively associated with birth weight and that their relationships should be further investigated. Using more sensitive measures for greenness and taking into account green space functionality and quality, as well as individual connectedness to nature, might yield clearer picture, higher statistical power and more precise results. Environmental exposures should also be adjusted for in future studies. Better statistical reporting is warranted.

Appendix A. Appendix A

Sample size: 1 – completely satisfactory/justified by power analysis; 0.5 – somewhat satisfactory; 0 – not sufficient/not justified.

Design: 1 – cohort; 0.75 – case-control; 0.25 – cross-sectional/ecological

Country where the study was carried out: 1 – with good working and living conditions/high socio-economic standard; 0.5 – difficult conditions/lower socio-economic standard; 0.25 – very difficult conditions/very low socio-economic standard; 0 – not reported.

Timeframe: 1 – reported; 0 – not reported.

Response rate: 1 – ≥80%/considerable part of the population; 0.75 – 60 to 80%; 0.5 – <60%; 0 – not reported.

Definition of birth weight: 1 – birth weight in absolute units (g, etc.); 0.25 – low birth weight/small for gestational age.

Assessment of birth weight: 1 – medical records/physician's exam/valid database; 0.25 – self-report; 0 – not specified.

Assessment of residential greenery: 1 – GIS buffer analysis considering landuse; 0.75 – GIS buffer NDVI/spectral reflectance aerial imagery; 0.5 – not study-specific official records; 0.25 – self-report.

Bio-phsyco-social plausibility given the exposure and outcome measures: 1 – undisputable associations; 0.75 – plausible; 0.25 – speculative; 0 – not plausible.

Adjustments for personal covariates (cov): 1 – 7 to $9_{(cov)}$ including smoking status; 0.75 – 4 to $6_{(cov)}$ including smoking status; 0.5 – 1 to $3_{(cov)}$ including smoking status; 0.25 – 5 to $9_{(cov)}$ without smoking status; 0.1 – 1 to $4_{(cov)}$ without smoking status; 0 – no covariates.

According to Croteau (2009), relevant confounders for birth weight and small for gestational age are: maternal age, obstetric history, socio-economic class, BMI, smoking, alcohol, infections, chronic diseases, congenital abnormalities. The scoring above indicates the score, given the number of covariates adjusted for, and whether smoking was one of them.

Adjustments for environmental covariates: 1 – air pollution (PM_{10}/$PM_{2.5}$ + NO_x/NO_2) + noise + walkability; 0.5 – one or two of air pollution/noise/walkability, 0 – no adjustments.

Effect size calculation for meta-analysis based on correlation coefficients: 1 – no transformations and no data imputation; 0.75 – mild transformation and no data imputation; 0.5 – several transformations and no data imputation, 0.25 – considerable transformations and data imputation

Appendix B. Appendix B

Because seven of the studies reported multivariate linear regressions we used the following formulae to convert the unstandardized regression coefficients into correlation coefficient (r):

$r = 0.98 \times \beta + 0.05 \times \lambda$ (Peterson and Brown, 2005)where β is standardized regression coefficient and λ is indicator variable equal to 1 when $\beta \geq 0$ and to 0 when $\beta < 0$.

$$\beta = \left(\frac{SD_{(x)}}{SD_{(y)}}\right) \times B$$

(Nieminen et al., 2013) where B stands for unstandardized regression coefficient, y is the outcome variable (indicator for birth weight) in the regression and x is the predictor of interest (indicator for residential greenery).

$SD_{(NDVI)}$ was calculated by either one of the two formulae given the reported data:

$SD_{(NDVI)} = \frac{IQR_{(100-m\ buffer)}}{1.349}$ (Nieminen et al., 2013)where IQR stands for Interquartile range of NDVI for 100 m buffer.

$$SD_{(NDVI)} = \frac{\left(75th\ \ percentile_{(100-m\ \ buffer)} - 25th\ \ percentile_{(100-m\ \ buffer)}\right)}{1.349}$$

where the difference of the two percentiles is equal to IQR.

When SD for birth weight was not reported and could not be obtained from previous studies analysing the same dataset (Laurent et al., 2013), it was imputed as equal to the averaged SD of birth weight across the other included studies:

$SD_{(birth\ weight)}$ = mean $SD_{(birth\ weight)}$ of the other included studies

For the only study reporting solely OR (Donovan et al., 2011) we converted OR to r with Excel spreadsheet based on Yule's transformation (www.stat-help.com).

For the meta-analysis based on β, the following formulae were applied for obtaining standardized regression coefficients and the corresponding standard errors:

$\beta = \frac{(OR-1)}{(OR+1)}$ (Kupek, 2006)

where OR – odds ratio. The same formula was also used to calculate the 95% CI for β.

$SE_{(B)} = \frac{(Upper\ \ 95\%\ \ CI - Lower\ \ 95\%\ \ CI)}{3.92}$ (http://handbook.cochrane.org/chapter_7/7_7_7_2_obtaining_standard_errors_from_confidence_intervals_and.htm).

$SE_{(b)} = \left(\frac{SD_{(x)}}{SD_{(y)}}\right) \times SE_{(B)}$ (Nieminen et al., 2013)

Appendix C. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ufug.2014.09.004.

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