

Neighbourhood context and its contribution to urban health inequalities

Dissertation

University of Bremen

Faculty of Human and Health Sciences

May 2017

Submitted by

Steffen Andreas Schüle

For the academic degree of Doctor Public Health (Dr. PH)

Supervisor: Prof. Dr. Gabriele Bolte

First reviewer: Prof. Dr. Hajo Zeeb

Second reviewer: Prof. Dr. Susanne Moebus

Defended on: 11th July 2017

Content

SINGLE PUBLICATIONS FOR CUMULATIVE DISSERTATION	III
TABLES.....	IV
FIGURES.....	IV
ABBREVIATIONS.....	V
ABSTRACT (ENGLISH).....	VI
ABSTRACT (GERMAN).....	VII
1 BACKGROUND.....	1
1.1 CONTEXTUAL APPROACHES EXPLAINING HEALTH INEQUALITIES.....	1
1.2 EXPLANATORY CONCEPTS FOR NEIGHBOURHOOD HEALTH INEQUALITIES	4
1.3 ENVIRONMENTAL INEQUALITIES.....	7
1.4 QUANTIFYING NEIGHBOURHOOD HEALTH EFFECTS – EVIDENCE FROM MULTILEVEL STUDIES	10
1.5 PROPOSING A CONCEPTUAL MODEL DESCRIBING PATHWAYS OF NEIGHBOURHOOD HEALTH INEQUALITIES.....	13
2 RESEARCH OBJECTIVES	17
2.1 INDEPENDENT AND INTERACTIVE EFFECTS OF SOCIOECONOMIC AND OBJECTIVE BUILT ENVIRONMENTS ON INDIVIDUAL HEALTH	17
2.2 CONTEXTUAL NEIGHBOURHOOD EFFECTS ON CHILD OVERWEIGHT.....	17
2.3 ENVIRONMENTAL NEIGHBOURHOOD INEQUALITIES IN URBAN CONTEXTS	18
3 DATA DESCRIPTION	19
3.1 HEALTH MONITORING UNITS IN MUNICH	19
3.2 SOCIOECONOMIC AND ENVIRONMENTAL NEIGHBOURHOOD DATA FROM THE CITY OF MUNICH	20
3.3 SOCIOECONOMIC AND ENVIRONMENTAL NEIGHBOURHOOD DATA FROM THE CITY OF DORTMUND.....	23
4 APPLIED METHODS.....	24
4.1 SYSTEMATIC REVIEW.....	24
4.2 CONTEXTUAL NEIGHBOURHOOD EFFECTS ON CHILD OVERWEIGHT.....	25
4.2.1 <i>Principal component analysis</i>	25
4.2.2 <i>Multilevel logistic regression</i>	25
4.2.3 <i>Multiple imputation of income data</i>	26
4.3 ENVIRONMENTAL NEIGHBOURHOOD INEQUALITIES	27
4.3.1 <i>Generalized linear models (Munich)</i>	27

4.3.2	<i>Correlation analysis (Dortmund)</i>	28
5	SUMMARY OF RESULTS	29
5.1	EVIDENCE ON INDEPENDENT AND INTERACTIVE HEALTH EFFECTS OF NEIGHBOURHOOD CONTEXTS	29
5.2	NEIGHBOURHOOD CONTEXT AND OVERWEIGHT IN CHILDREN	35
5.3	ENVIRONMENTAL INEQUALITIES ON THE NEIGHBOURHOOD LEVEL	36
5.4	SOCIOECONOMIC DISPARITIES OF NEIGHBOURHOOD PUBLIC GREEN SPACE	37
6	DISCUSSION AND CRITICAL REFLEXIONS OF METHODS AND RESULTS	39
6.1	EVIDENCE ON PATHWAYS BETWEEN NEIGHBOURHOOD CONTEXTS AND INDIVIDUAL HEALTH.....	39
6.2	CONTEXTUAL NEIGHBOURHOOD EFFECTS ON CHILD OVERWEIGHT.....	44
6.3	SOCIOECONOMICALLY DRIVEN ENVIRONMENTAL NEIGHBOURHOOD INEQUALITIES.....	48
7	OVERALL CONCLUSIONS	53
8	REFERENCES	54
9	ACKNOWLEDGEMENTS	70
ANNEX A	PUBLICATIONS FOR CUMULATIVE DISSERTATION	71
ANNEX A.1	INTERACTIVE AND INDEPENDENT ASSOCIATIONS BETWEEN THE SOCIOECONOMIC AND OBJECTIVE BUILT ENVIRONMENT ON THE NEIGHBOURHOOD LEVEL AND INDIVIDUAL HEALTH: A SYSTEMATIC REVIEW OF MULTILEVEL STUDIES	72
ANNEX A.2	NEIGHBOURHOOD SOCIOECONOMIC CONTEXT, INDIVIDUAL SOCIOECONOMIC POSITION, AND OVERWEIGHT IN YOUNG CHILDREN: A MULTILEVEL STUDY IN A LARGE GERMAN CITY.....	112
ANNEX A.3	BUILT AND SOCIOECONOMIC NEIGHBOURHOOD ENVIRONMENTS AND OVERWEIGHT IN PRESCHOOL AGED CHILDREN. A MULTILEVEL STUDY TO DISENTANGLE INDIVIDUAL AND CONTEXTUAL RELATIONSHIPS	122
ANNEX A.4	RELATIONSHIP BETWEEN NEIGHBOURHOOD SOCIOECONOMIC POSITION AND NEIGHBOURHOOD PUBLIC GREEN SPACE AVAILABILITY: AN ENVIRONMENTAL INEQUALITY ANALYSIS IN A LARGE GERMAN CITY APPLYING GENERALIZED LINEAR MODELS.....	132
ANNEX A.5	MAPPING ENVIRONMENTAL INEQUALITIES RELEVANT FOR HEALTH FOR INFORMING URBAN PLANNING INTERVENTIONS-A CASE STUDY IN THE CITY OF DORTMUND, GERMANY.	141
ANNEX B	AUTHOR CONTRIBUTIONS	161
ANNEX C	FURTHER PUBLICATIONS, POSTERS, AND ORAL PRESENTATIONS	163
ANNEX D	EIDESSTÄTLICHE ERKLÄRUNG	165

Single publications for cumulative dissertation

This framework document is based on the five following publications:

1. **Schüle, S. A., & Bolte, G. (2015).** Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: a systematic review of multilevel studies. *PloS One*, *10*(4), e0123456. doi: 10.1371/journal.pone.0123456
2. **Schüle, S. A., von Kries, R., Fromme, H., & Bolte, G. (2016).** Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: a multilevel study in a large German city. *BMC Obesity*, *3*, 25. doi: 10.1186/s40608-016-0106-4
3. **Schüle, S. A., Fromme, H., & Bolte, G. (2016).** Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. *Environmental Research*, *150*, 328-336. doi: 10.1016/j.envres.2016.06.024
4. **Schüle, S. A., Gabriel, K.M.A., & Bolte, G. (2017).** Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: an environmental inequality analysis in a large German city applying generalized linear models. *International Journal of Hygiene and Environmental Health*, *220*(4), 711-718. doi: 10.1016/j.ijheh.2017.02.006
5. **Flacke, J., Schüle, S. A., Köckler, H., & Bolte, G. (2016).** Mapping environmental inequalities relevant for health for informing urban planning interventions-a case study in the city of Dortmund, Germany. *International Journal of Environmental Research and Public Health*, *13*(7). doi: 10.3390/ijerph13070711

Tables

Table 1 Number of observations per survey	20
Table 2 Socioeconomic characteristics of selected school districts in the city of Munich (2006/07)	21
Table 3 Socioeconomic neighbourhood characteristics in the city of Munich (2011-2013) ...	21
Table 4 Socioeconomic neighbourhood characteristics in the city of Dortmund (2013/14)....	23
Table 5 Number of associations between neighbourhood contexts and physical activity	32
Table 6 Number of associations between neighbourhood contexts and overweight	33
Table 7 Number of associations between neighbourhood contexts and health problems and health behaviours.....	34
Table 8 Number of associations between neighbourhood contexts and child health.....	34

Figures

Figure 1 Conceptual model linking socioeconomic position, environment, and health	8
Figure 2 Conceptual model describing multilevel pathways of neighbourhood health inequalities	16
Figure 3 Number of studies identified by country	29
Figure 4 Number of studies identified by health outcomes and health behaviours	31

Abbreviations

AIC	Akaike information criterion
BIC	Bayesian information criterion
BMI	Body mass index
CI	Confidence interval
GIS	Geographic information systems
GLM	Generalized linear models
GME	Health monitoring units (Gesundheits-Monitoring-Einheiten)
MOR	Median odds ratio
NO ₂	Nitrogen dioxide
NO _x	Nitrogen oxides
PCA	Principal component analysis
PCV	Proportional change in variance
PM ₁₀	Particulate matter
SEP	Socioeconomic position
VIF	Variance inflation factor
WHO	World Health Organization

Abstract (English)

The neighbourhood environment in which people live has gained increasing attention in epidemiological research. This dissertation investigated relationships between contextual neighbourhood factors and individual health with a focus on the built environment and its contribution to health inequalities on the neighbourhood level. Furthermore, this dissertation developed new approaches and applied new statistical methods to analyse environmental inequalities in an urban context with a particular focus on public green space and its distribution by socioeconomic neighbourhood characteristics.

Firstly, in a systematic review multilevel studies which considered both neighbourhood socioeconomic position (SEP) and objectively measured factors of the built environment were assessed in order to disentangle their independent and interactive effects on individual health outcomes and health behaviours. Secondly, two multilevel analyses of cross-sectional data in the city of Munich investigated whether neighbourhood SEP, public playground and park space, and parentally perceived environmental exposures were independently associated with overweight in preschool aged children while simultaneously considering individual child and family factors. Thirdly, two ecological neighbourhood studies in the city of Dortmund and Munich were conducted to assess whether air and noise pollution and public green space were disproportionately distributed by the degree of neighbourhood deprivation.

The systematic review identified a great heterogeneity of definitions applied and metrics being used for measuring built and socioeconomic neighbourhood variables. Mostly mixed results across multilevel studies on how built and socioeconomic neighbourhood environments were associated with health and health-related behaviours were found. Furthermore, the review identified several interactions between contextual neighbourhood factors and individual factors, mostly concerning sex or individual SEP. The two multilevel studies showed that in the case of childhood overweight individual factors, such as parental education or parental overweight, were the most important determinants. However, perceived and objective built environmental factors additionally explained overweight variance between neighbourhoods. The two ecological case studies found out that deprived neighbourhoods were more exposed to air pollution and low public green space availability than more affluent neighbourhoods.

This dissertation recommends that apart from individual determinants policies and interventions targeting health promotion should consider the neighbourhood environment additionally. Moreover, a socioeconomic unequal distribution of environmental burdens and resources may result in amplifications of health inequalities within cities. There is a need for further studies considering multiple neighbourhood dimensions in order to analyse interactive and mediating pathways between contextual factors and individual health. The development of new approaches and methods for analysing and assessing environmental health inequalities will contribute to the reconnection of urban planning and public health.

Abstract (German)

Kontextfaktoren im Stadtteil und deren gesundheitliche Bedeutung sind in der epidemiologischen Forschung zunehmend von Interesse. Diese Dissertation untersuchte Zusammenhänge zwischen kleinräumigen Faktoren der gebauten Umwelt und individueller Gesundheit und deren Beitrag zu gesundheitlichen Ungleichheiten in Städten. Des Weiteren wurden neue Verfahren und statistische Methoden zur Analyse von Umweltfaktoren, mit dem Fokus auf öffentliches Grün, und deren Verteilung nach sozioökonomischen Merkmalen von Stadtteilen angewandt.

In einem systematischen Review wurden Multilevelstudien identifiziert, welche sowohl die sozioökonomische Position des Stadtteils als auch objektive Faktoren der gebauten Umwelt berücksichtigten, um sowohl deren unabhängigen als auch interaktiven Effekte auf die individuelle Gesundheit zu untersuchen. In zwei Multilevelanalysen mit Querschnittsdaten der Stadt München wurde des Weiteren analysiert inwieweit die sozioökonomische Position des Stadtteils, öffentliche Spielplätze und Parkanlagen, sowie subjektiv wahrgenommene Umweltbelastungen mit Übergewicht bei Kindern assoziiert waren. Wichtige kindliche und elterliche Faktoren wurden dabei simultan mitberücksichtigt. Darüber hinaus wurde in zwei ökologischen Studien in Dortmund und München untersucht inwieweit Luft- und Lärmverschmutzung, sowie die Verfügbarkeit von öffentlichen Grünflächen disproportional nach dem Grad der sozioökonomischen Benachteiligung von Stadtteilen verteilt waren.

Der systematische Review identifizierte eine sehr große Heterogenität an Definitionen welche für die Berechnung der Variablen, insbesondere der gebauten Umwelt, verwendet wurden. Meist wurden gemischte Ergebnisse gefunden inwieweit die gebaute Umwelt und die sozioökonomische Position des Stadtteils mit gesundheitlichen Zielgrößen und Verhaltensweisen assoziiert waren. Darüber hinaus identifizierte der systematische Review eine Vielzahl an Interaktionen zwischen kontextuellen und individuellen Faktoren, meist das Geschlecht oder die individuelle sozioökonomische Position betreffend. Die zwei Multilevelanalysen zeigten, dass individuelle Faktoren, wie z.B. elterliche Bildung und elterliches Übergewicht, die wichtigsten Determinanten für kindliches Übergewicht waren. Jedoch klärten wahrgenommene und objektive Faktoren der gebauten Umwelt zusätzliche Varianz von Übergewicht zwischen Stadtteilen auf. Die zwei ökologischen Studien fanden eine sozioökonomisch ungleiche Verteilung von Luftverschmutzung und öffentlichen Grünflächen.

Diese Dissertation empfiehlt, dass Strategien und Maßnahmen zur Gesundheitsförderung neben individuellen Determinanten auch zusätzlich Faktoren der unmittelbaren Stadtteilumwelt berücksichtigen sollten. Darüber hinaus kann eine sozioökonomisch ungleiche Verteilung von Umweltbelastungen und -ressourcen gesundheitliche Ungleichheiten im urbanen Raum verstärken. Weitere Studien sind notwendig, welche simultan unterschiedliche Dimensionen des Stadtteils berücksichtigen um sowohl interagierende als auch intermediäre Pfade zwischen Kontextfaktoren und individueller Gesundheit zu analysieren. Die Entwicklung neuer Methoden zur Analyse sozioökonomisch bedingter Ungleichheiten bei Umwelt und Gesundheit kann hierbei die transdisziplinäre Zusammenarbeit zwischen Stadtplanung und Public Health fördern.

1 Background

1.1 Contextual approaches explaining health inequalities

The inextricable link between socioeconomic inequalities and health inequalities is widely recognized and was proven in a large number of studies (Black et al., 1980; Marmot, 2005; Mielck, 2005; Siegrist & Marmot, 2006; Whitehead, 1987). Knowledge of mechanisms which explain socioeconomic inequalities in health are important for understanding and studying geographic health inequalities on the neighbourhood level.

The term health inequalities has a descriptive character and should be distinguished from the term health inequities which includes normative concepts. Health inequalities are defined as observed health differences between populations in general, such as different distributions of health outcomes between different socioeconomic groups. Health inequalities become inequities when they are perceived as unfair, unjust, and avoidable (WHO, 2016a, 2016c). Determining health inequalities as inequities comprises more than empirical evidence because it includes normative judgement. Society, politics, and science determine which part of health inequalities are judged as inequitable (Kawachi et al., 2002; Mielck, 2005). Therefore, the term health inequality is used in this dissertation. The epidemiological studies performed contribute to the scientific evidence on neighbourhood health inequalities. They do not include additional analyses to what extent observed geographic health inequalities are judged or perceived as health inequities.

Moreover, the term socioeconomic position (SEP) is used in this dissertation. As suggested by Krieger et al. the term SEP combines actual economic and social resources with prestige-based characteristics which relatively position individuals, households, or neighbourhoods in society (Krieger, 2001a; Krieger et al., 1997). To avoid discrepancies, the term SEP is differentiated from social factors or social environments in this dissertation which refer to social interactions between individuals in society, such as social cohesion, social capital, or collective efficacy (Diez Roux & Mair, 2010; Leventhal & Brooks-Gunn, 2000; Sampson et al., 1999; Sampson et al., 2002; Schreier & Chen, 2013).

The term social determinants, introduced by the World Health Organization (WHO), is an exception as this term contains a more holistic perspective. The social determinants of health include “*the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life*” (WHO, 2016b). Individual

behaviours, psychosocial mechanisms, and material factors were identified as the most important determinants which explain socioeconomic inequalities in health.

Material explanations for socioeconomic inequalities in health look mainly at living conditions, resources for a healthy life, and availability of health services. Furthermore, material explanations assume that people with a low SEP are exposed to an unhealthy environment. Individual explanations for socioeconomic inequalities in health include behaviours, cultural characteristics, or psychosocial factors. It is hypothesized that people with a low SEP have more often unhealthy behaviours or a higher psychosocial workload (Richter & Hurrelmann, 2006).

Various conceptual models have been developed describing pathways between socioeconomic and health inequalities and how determinants on various levels influence individual health. One of the first models describing various determinants of health was developed by Dahlgren and Whitehead (Dahlgren & Whitehead, 1991). Four main levels of determinants are imaged as layers on top of each other. The first overall layer represents main structural factors, such as general socioeconomic, environmental, or cultural conditions in society. The second layer includes living and working conditions, such as employment status or housing, followed by the third layer representing social and community factors, such as support through neighbours or friends. The last layer contains individual factors, such as behaviours, and the core represents factors which are assumed to be fixed, such as age or sex. Inspired by the rainbow model, Barton and Grant developed a health map reflecting the ecosystem of the human habitat with a particular focus on multilevel neighbourhood determinants influencing health and well-being (Barton & Grant, 2006).

In Germany there are two conceptual models describing pathways of socioeconomic health inequalities which are important to mention. The models from Elkeles and Mielck and Steinkamp consider various factors on different levels which lead to health inequalities in societies (Elkeles & Mielck, 1993; Steinkamp, 1999). The macrolevel considers mainly factors which determine the SEP of people within a society assessed by income, education, or occupation. On the mesolevel material and social characteristics are considered as intermediating factors which in turn influence individual behaviours and finally individual health. The model by Steinkamp put more focus on the microlevel which contains individual factors, such as personal resources, coping strategies, or genetic factors.

The Commission on Social Determinants of Health initiated by the WHO developed a conceptual framework which comprises two main levels being responsible for health inequalities. The first level contains the structural determinants, defined by the wider socioeconomic and political context in society, which in turn determine the SEP of individuals. The second level, the so called intermediary determinants, contains mainly material circumstances, individual behaviours, and psychosocial factors. Social factors, such as social capital or social cohesion, are assumed to be linked with both levels (WHO, 2010).

All these models presented above have important similarities. Firstly, all models involve a hierarchical structure with various contextual levels which individuals are exposed to determining their SEP, living conditions, behaviours, and finally their health status. Furthermore, all levels ranging from various contextual levels to the individual level are not considered isolated because they interact with each other. Secondly, for determining SEP mainly vertical characteristics are used. Examples of vertical factors are income, occupation, or education. A combination with so called horizontal factors, such as ethnicity, age, or gender is recommended (Mielck, 2000, 2005).

Nancy Krieger's ecosocial theory provides a good theoretical background underlining contextual pathways between socioeconomic inequalities and health inequalities. In 1994 Nancy Krieger suggested an ecosocial concept which mainly argued that humans are simultaneously biological and social beings and both the ecological and societal context are important to consider when patterns of socioeconomic related health inequalities are analysed (Krieger, 1994, 2011).

The most central part of ecosocial theory is the concept of embodiment. Embodiment claims *“that people literally embody, biologically, their lived experience, in societal and ecological context, thereby creating population patterns of health and disease”* (Krieger, 2011, page 215). Embodiment integrates the social determinants of health as exogenous factors influencing individual bodies and people's health.

Ecosocial theory considers various pathways of embodiment through which social or environmental exposures affect an individual's organism. These pathways are located on different temporal and spatial scales. Temporal scales include pathways across the life course shaped by historical contexts and generational aspects. Spatial scales consider various hierarchical levels (global, national, regional, area or group, household, or individual) which represent different ecological and social pathways of embodiment. Embodiment is influenced

by the distribution of environmental, political, economic, or social factors within and across these scales, such as societal power relations, ecosystems, or material goods. Furthermore, embodiment is dependent on individual biological capabilities and limitations which are in turn influenced by social and biological development.

A further core construct of ecosocial theory is that multiple pathways of embodiment, which take place on various spatiotemporal scales with varying distribution of exposures across these scales, involve a “*cumulative interplay between exposure, susceptibility, and resistance*” (Krieger, 2001b, page 672). This core construct emphasize the accumulation of, timing of, and individual response to embodied exposures.

Accountability and agency, as a final core construct, put emphasis on instruments and ways how health inequalities are monitored and analysed. Individuals, political and economic institutions, and epidemiologists in particular are addressed with their capabilities and responsibilities across levels in taking actions for explaining and reducing socioeconomic inequalities in health.

All conceptual models described in this chapter state that explaining patterns of health inequalities requires the consideration of multiple contextual determinants. Therefore, they provide a good basis for the development of specific concepts focusing on small area factors as potential drivers for health inequalities in urban contexts.

1.2 Explanatory concepts for neighbourhood health inequalities

There is an overall conclusion that individual characteristics, such as individual SEP or individual behaviours, are not sufficient for explaining inequalities in health. Integrating contextual determinants from the social, physical, or political environment to which individuals or groups of people are exposed gained increasing attention in epidemiological and public health research (McLaren & Hawe, 2005).

The neighbourhood level has become an important contextual dimension. Neighbourhoods hold social and physical factors which are assumed to be associated with individual health of residents sharing these neighbourhood characteristics. Moreover, neighbourhoods are often used as references for urban planning interventions, routine data collection and monitoring, and political decision making processes. However, providing a clear definition of the term neighbourhood is still challenging (Galster, 2001). Often, terms such as community, small

area, or place are used interchangeably. Mostly, these terms refer to the usage of administrative boundaries and its available census data.

In the last twenty years the number of studies investigating independent neighbourhood effects on health rapidly increased. As a result, three main explanatory pathways were derived explaining health inequalities between neighbourhoods.

Firstly, health variations between neighbourhoods can be attributed to compositional effects which capture individual characteristics of residents, such as SEP or behaviours. Secondly, geographic health variations can be attributed to contextual effects mainly attributed to environmental characteristics from the built or social environment which neighbourhood residents share. In addition, there might be a contextual effect of group composition if aggregated individual factors on the area level, such as neighbourhood SEP, are associated with individual health independent of individual factors of residents within the neighbourhood. In this dissertation neighbourhood SEP is therefore defined as a contextual factor if individual socioeconomic characteristics are simultaneously considered in multivariate analyses.

A third explanation refers to the collective dimension shared by neighbourhood residents. It includes anthropological characteristics, such as shared norms, common interests, and values. In neighbourhood research contextual factors from the neighbourhood environment gained most interest because it is assumed that physical or social attributes explain contextual health effects of group composition. (Diez Roux & Mair, 2010; Duncan et al., 1998; Macintyre et al., 2002).

The differentiation between composition and context is also discussed critically in the scientific literature. Macintyre and Ellaway argued: *“People create places and places create people”* (Macintyre & Ellaway, 2003, page 26). Arguments for the mutual dependencies between individuals and contexts are that individual characteristics are shaped by contextual characteristics, such as individual education may be dependent from the local contextual school system, or occupational status from the local labour market. Furthermore, it is argued that in multivariate analysis individual factors are often treated as confounders although they might be intervening or mediating factors on the pathway between neighbourhood context and health, such as health behaviours or household characteristics. Related to this problem are missing a priori theories which conceptualize causal mechanisms between health and place

which justify the selection of contextual or individual characteristics (Cummins et al., 2007; Macintyre et al., 2002).

For strategy development and policy making the quantification of contextually initiated health inequalities on the neighbourhood level build an important prerequisite for intervention planning targeting health-promoting built and social environments. Furthermore, evidence on how built environmental factors are independently associated with health and contribute to health inequalities between neighbourhoods supports a better reconnection between urban planning and public health (Corburn, 2004).

Various explanatory models have been developed which conceptualize small area effects on health. A systematic review by Voigtländer et al. identified 14 studies which developed an explanatory model considering various theoretical backgrounds to outline how different neighbourhood characteristics affect specific health outcomes or behaviours of neighbourhood residents through different pathways (Voigtländer et al., 2014). The review identified the following similarities across models:

- Neighbourhood differences in exposures to environmental resources and stressors contribute to geographic health inequalities
- There is no clear definition of the term small-area or neighbourhood context
- Neighbourhood context is mostly differentiated in the built and social environment
- There are multiple pathways linking contextual neighbourhood factors and individual health, such as cognitive factors determining allostatic load or behaviours, direct pathways of environmental stressors or resources affecting health, or indirect pathways which include contextual effects on individual SEP or personal resources. As a result, individual characteristics of neighbourhood residents and contextual factors may be not mutual exclusive and individual characteristics can both be an effect modifier or mediator on the pathway between context and individual health
- Socioeconomic segregation processes are identified as the most relevant drivers for variations in neighbourhood characteristics. As a result, models followed a three level structure representing socioeconomic inequalities at the macrolevel, neighbourhood characteristics at the mesolevel, and individual characteristics at the microlevel

The identified levels and their included factors and pathways linking neighbourhood context and health showed that both contextual and individual characteristics contribute to health inequalities between neighbourhoods. For the quantification of contextual neighbourhood

effects and their contribution to health inequalities a simultaneous consideration of these two levels is required in statistical modelling. Furthermore built environmental factors play an essential role across all conceptual models described above. Especially for healthy city planning built environmental characteristics are a main basis for interventions on the interface between urban planning and public health.

1.3 Environmental inequalities

The potential amplification of geographic health inequalities through a socioeconomic unequal distribution of environmental stressors and resources is an important issue when neighbourhood health effects are analysed. The environmental justice movement, which had its origins in the USA and was initiated by activists, claimed that ethnic minorities were disproportionately exposed to hazards in their neighbourhood environment, such as to toxic waste sites or industry producing air and noise pollution (Brulle & Pellow, 2006).

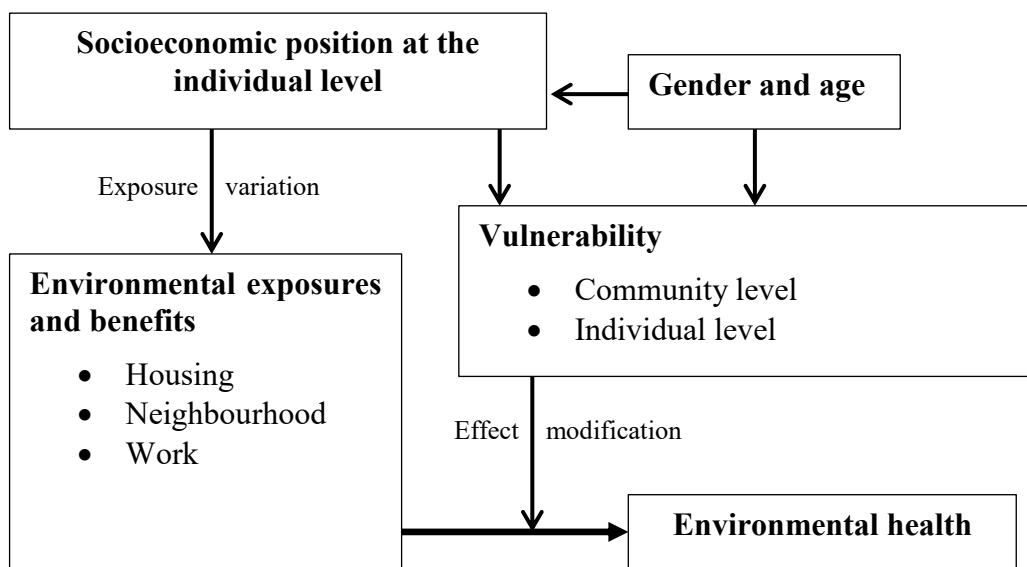
Environmental justice deals with actions on the improvement of living conditions of disadvantaged groups including cultural, behavioural, and political aspects. The term should be therefore distinguished from environmental inequalities which has a more structural focus. Environmental inequalities include a broader analysis of the distribution of environmental hazards or resources across societal groups in a more descriptive way (Pellow, 2000; Walker, 2012).

A conceptual model derived from the environmental justice framework by Bolte et al. broadened the scope of environmental inequalities as it includes both pathogenic and salutogenic elements and discussed various forms of vulnerability (Bolte et al., 2011). Concepts of vulnerability have their origins in natural hazard research and were further developed in other scientific fields, such as climate change research. *“Vulnerability is the degree to which a population or an individual is unable to anticipate, cope with, resist and recover from the impacts of disasters. It is a function of susceptibility and resilience”* (Adams & Wisner, 2002, page 5). Vulnerability and susceptibility are closely related terms, whereas in general vulnerability includes external environmental factors, and susceptibility comprises internal biological factors increasing individual health risk, such as genetics or age (Portier et al., 2010).

The conceptual model contains two main hypothetical pathways how individual SEP, environmental exposures, and environmental health at the individual level are connected (see figure 1). The first hypothesis states that environmental exposures and benefits are social

unequally distributed on various levels and in different settings, such as neighbourhood, housing, or work. The second hypothesis states that communities or individuals with a low SEP are more vulnerable to health effects of environmental exposures. Vulnerability on the community level includes both resources and burdens on the small area level, such as neighbourhood social capital, public transport, or accessibility of health service institutions. Vulnerability on the individual captures individual behaviours and characteristics on how environmental resources and burdens are incorporated, such as psychosocial factors, physiological mechanisms, or coping strategies.

Figure 1 Conceptual model linking socioeconomic position, environment, and health



Quelle: (Bolte et al., 2011) (own description)

Mechanisms of vulnerability which explain how SEP modifies associations between environmental exposures and health play an important role within the analysis and understanding of environmental health inequalities. Psychosocial stress is seen as one of the major factors modifying the individual level health impact of environmental community stressors (Gee & Payne-Sturges, 2004; Morello-Frosch & Shenassa, 2006).

Gee and Payne-Sturges argue that differences in the individual vulnerability to environmental burdens or resources is mainly caused by psychosocial stress. They developed a conceptual model which suggests that community level vulnerability is translated into individual stressors which increases individual stress and leads therefore to individual vulnerability (Gee & Payne-Sturges, 2004).

Chronic individual stress influenced by community level and individual stressors plays a major role in the explanatory model by Morello-Frosch and Shenassa, too (Morello-Frosch & Shenassa, 2006). Community stressors comprise factors from the built and social environment, and individual stressors include factors, such as SEP, working conditions, or health behaviours. Both stressor levels are mutually dependent from each other and are associated with chronic individual stress which in turn influences individual allostatic load. Allostasis comprises the capability of the body to regulate physiological mechanisms of the stress-response system when exposed to environmental stressors.

Early studies on environmental inequalities were conducted mainly in the USA in the 1970s, 1980s, and 1990s, and focused predominantly on single exposures from environmental pollutants. They found out that neighbourhoods with a high proportion of ethnic minorities were more exposed to air pollution, pesticides, or other chemical exposures coming from hazardous waste sites (Szasz & Meuser, 1997).

Since the beginning of the 21st century, the number of studies providing evidence on environmental inequalities has been increased in Europe. They considered multiple indicators describing SEP of individuals or neighbourhoods and incorporated a broader scope of health relevant environmental factors including both stressors and resources from the social and built environment. Most studies found a socioeconomic unequal distribution of environmental neighbourhood burdens and resources on various levels, such as the national, neighbourhood or individual level. Systematic reviews indicated that groups or neighbourhoods with a low SEP were more exposed to environmental hazards and had less access to environmental resources (Braubach & Fairburn, 2010; Kruize et al., 2014).

In terms of environmental resources and their potential health benefits, the socioeconomic related distribution of and access to urban green spaces within cities has received increasing attention in environmental justice research in the last years (Jennings et al., 2012; Wolch et al., 2014). Studies showed that a lower neighbourhood SEP was associated with decreasing availability of green space (Astell-Burt et al., 2014; Lakes et al., 2014; Richardson et al., 2010; M. Wen et al., 2013).

1.4 Quantifying neighbourhood health effects – Evidence from multilevel studies

Conceptual models, which were summarized in the previous chapters, describing mechanisms how health inequalities and environmental inequalities are connected suggest that epidemiological studies which are only based on individual data are not sufficient enough to explain geographic distributions of health outcomes. As a result, since the late 1990s there has been a rapid increase of epidemiological studies investigating the independent effect of contextual neighbourhood factors on individual health.

To analyse potential effects of neighbourhood contexts on individual health outcomes multilevel analysis offers an adequate modelling strategy. It provides the possibility to separate contextual or group-level effects from compositional effects. In this dissertation the term multilevel model is used. Terms like hierarchical models, random effects models, or mixed models are often used synonymously (Diez Roux, 2002).

A multilevel study design combines data on at least two hierarchical levels: aggregated or group variables on the neighbourhood level (2nd level) and variables on the individual level from residents within the neighbourhood (1st level). Thus, simultaneous examinations of independent effects of each level and interactions within and across levels on individual health outcomes are possible while accounting for the potential dependency of individual observations sharing the same characteristics of higher group level variables. Therefore, multilevel modelling combines ecological with individual data and reduces the risk of an ecological fallacy when associations between group-level variables and response variables on the individual level are analysed.

Furthermore, multilevel analysis offers the possibility to examine group-to-group variability. In neighbourhood studies the contribution of contextual factors to health inequalities between areas in relation to individual factors can be quantified. This is achieved through random intercepts or random slopes. Random intercepts, also called variance components, allow the averaged fixed intercept to vary randomly across neighbourhoods which is one of the more simpler multilevel models because it is assumed that the parameter estimates of the individual and contextual covariables are similar across neighbourhoods which means that there is no effect modification. In random-slope models in addition to the intercept the slope may also vary across neighbourhoods which allows to identify cross-level interactions between contextual and individual factors (Diez Roux, 2000; Duncan et al., 1998; Subramanian et al., 2003).

A great amount of previous studies investigated whether aggregated individual socioeconomic characteristics, describing neighbourhood SEP on the area level, showed an independent contextual association with individual mortality, morbidity, or health behaviours through the adjustment for relevant factors on the individual level.

One of the first systematic reviews on contextual neighbourhood effects was conducted by Pickett and Pearl considering studies before 1998 which investigated the independent influence of neighbourhood SEP on individual health (Pickett & Pearl, 2001). In 23 of 25 studies independent significant associations between at least one factor describing neighbourhood SEP and individual health were found while adjusting for individual socioeconomic characteristics. Socioeconomic neighbourhood deprivation was independently associated with a worse state of individual health and health behaviours, such as higher mortality, lower birthweight, lower self-rated health, higher body mass index (BMI), and increased smoking or alcohol consumption.

A following review by Riva, Gauvin, and Barnett confirmed a marked increase of multilevel neighbourhood studies from 1998 until 2005 and identified 88 multilevel studies analysing neighbourhood effects on self-rated health, cardiovascular diseases and related risk factors, and mortality (Riva et al., 2007). Most studies detected an independent significant association between indicators describing a low neighbourhood SEP and a lower self-rated health status, increased mortality, and higher risk of cardiovascular diseases and related risk factors, such as overweight, unhealthy diet, or increased smoking.

More recent reviews and meta-analyses summarizing and analysing results from multilevel neighbourhood studies confirmed results from these earlier reviews. A meta-analysis considering multilevel neighbourhood studies found an independent association between a lower neighbourhood SEP and increased mortality whereas a systematic review within the same study indicated mixed findings (Meijer et al., 2012).

A systematic review by Sellström and Bremberg identified 13 multilevel studies from 1990-2005 which studied the impact of neighbourhood factors on child and adolescent health. The review calculated that across studies on average 10 % between-neighbourhood-variance of the health outcome was explained by contextual neighbourhood factors after adjusting for individual variables. Health outcomes in this review were mainly problem behaviours, child maltreatment, injuries, and birth weight (Sellström & Bremberg, 2006). Aggregated socioeconomic data from neighbourhood residents were the predominant factors used for

describing neighbourhood context. A further meta-analysis of multilevel studies by Metcalfe et al. on infant health found a significant contextual neighbourhood effect between low neighbourhood income and low birthweight (Metcalfe et al., 2011).

Evidence from multilevel neighbourhood studies so far showed that neighbourhoods are an ecological determinant of individual health and could therefore play an important role as a setting where health interventions could take place. However, there are still many open issues which need to be addressed in further multilevel studies. The following challenges are of particular interest.

Previous multilevel studies mostly focused on analysing and reporting independent associations between neighbourhood context and individual health whereas variance components mostly had not been adequately addressed. There is a need for further multilevel studies which quantify the contribution of contextual factors to neighbourhood health inequalities.

There is still a great heterogeneity across multilevel studies which and how many individual factors are considered for adjustment, especially for individual SEP characteristics. As a result, contextual effect estimates may be over or underestimated and are difficult to compare between studies.

Furthermore, on the neighbourhood level often single factors describing neighbourhood SEP were used, such as vertical measures of income, education, and occupation, or horizontal measures, such as ethnicity. Single measures of neighbourhood SEP may not adequately represent all relevant socioeconomic dimensions. A combination of various measures offers a potential solution. However, neighbourhood SEP factors often show multicollinearity which needs to be addressed through adequate methods, such as principal component analysis (PCA).

Besides characteristics describing neighbourhood SEP, which were most exhaustively used in multilevel studies, the built environment gained increasing attention when health inequalities on the neighbourhood level were analysed. Systematic reviews considered primarily cardiovascular risk factors, such as overweight and obesity, or low physical activity. Food environments, physical activity resources, aspects of neighbourhood safety, and features which increase walkability were the main built environmental dimensions which were analysed (Ding et al., 2011; Feng et al., 2010a; Galvez et al., 2010; Renalds et al., 2010; Van Holle et al., 2012). Though results of these studies were mixed, there is an overall conclusion

that the built environment can significantly impact individual health independent from individual factors. Although both neighbourhood SEP and built environmental factors play a significant role for explaining health inequalities between neighbourhoods, both dimensions had been rarely considered simultaneously in systematic reviews.

Finally, previous reviews showed a lack of multilevel studies targeting child health and the influence of potential neighbourhood characteristics of the socioeconomic or built environment. Children are more vulnerable to environmental burdens than other population groups and should be therefore considered more often in multilevel neighbourhood studies (Tamburlini, 2002).

1.5 Proposing a conceptual model describing pathways of neighbourhood health inequalities

Based on the previous chapters summarizing models and theories describing pathways how neighbourhood health inequalities occur, a conceptual model was developed (see figure 2). One of the main targets of this model was to disentangle contextual neighbourhood factors from individual factors and to conceptualize their potential direct and indirect pathways towards individual health. A further goal was to integrate neighbourhood SEP and individual SEP in one model in order to conceptualize their different meanings and potentials for analysing neighbourhood health inequalities which has been rarely done in previous models.

As already suggested in previous studies and models, a three level structure was implemented. The macrolevel represents structural contextual factors influencing the distribution of wealth within a society which in turn influences residential segregation processes. Macrolevel factors are primarily from the governmental and political context. Policies include economic policies, such as trade policies or labour markets, social policies, such as welfare factors or land and housing distribution, and public policies, such as education or health care services (WHO, 2010).

The mesolevel represents the neighbourhood context containing the most three important dimensions for health and their determinants on the individual level. Neighbourhood SEP represents combined or single aggregated factors describing the SEP of the neighbourhood. Aggregated individual data on employment, income, or education play an important role for describing social disadvantages of neighbourhoods and are increasingly used for calculating neighbourhood deprivation indices (Lalloue et al., 2013; Messer et al., 2006; Pampalon et al., 2012; Pampalon et al., 2009). The terms built environment and physical environment are

often used interchangeably. In a definition by Schulz and Northridge the built environment represents that part of the physical environment which “*encompass all of the buildings, spaces, and products that are created or significantly modified by people (...)*” (Schulz & Northridge, 2004, page 456). As the conceptual model refers to health inequalities in an urban context, the term built environment is used because it is assumed that within cities most of the environmental burdens and resources are man-made. The social environment comprises factors describing social connections, such as social capital, violence, social norms, or trust (Diez Roux & Mair, 2010; Schreier & Chen, 2013).

All three neighbourhood dimensions cannot be regarded isolated from each other. There is a contextual effect of neighbourhood SEP if multilevel analysis detects an independent association between neighbourhood SEP and individual health while all relevant characteristics on the individual level (microlevel), especially individual SEP, are taken into account as potential confounders. Underlying factors of the social and built environment are conceptualized as mediating factors on the pathway between neighbourhood SEP and the microlevel.

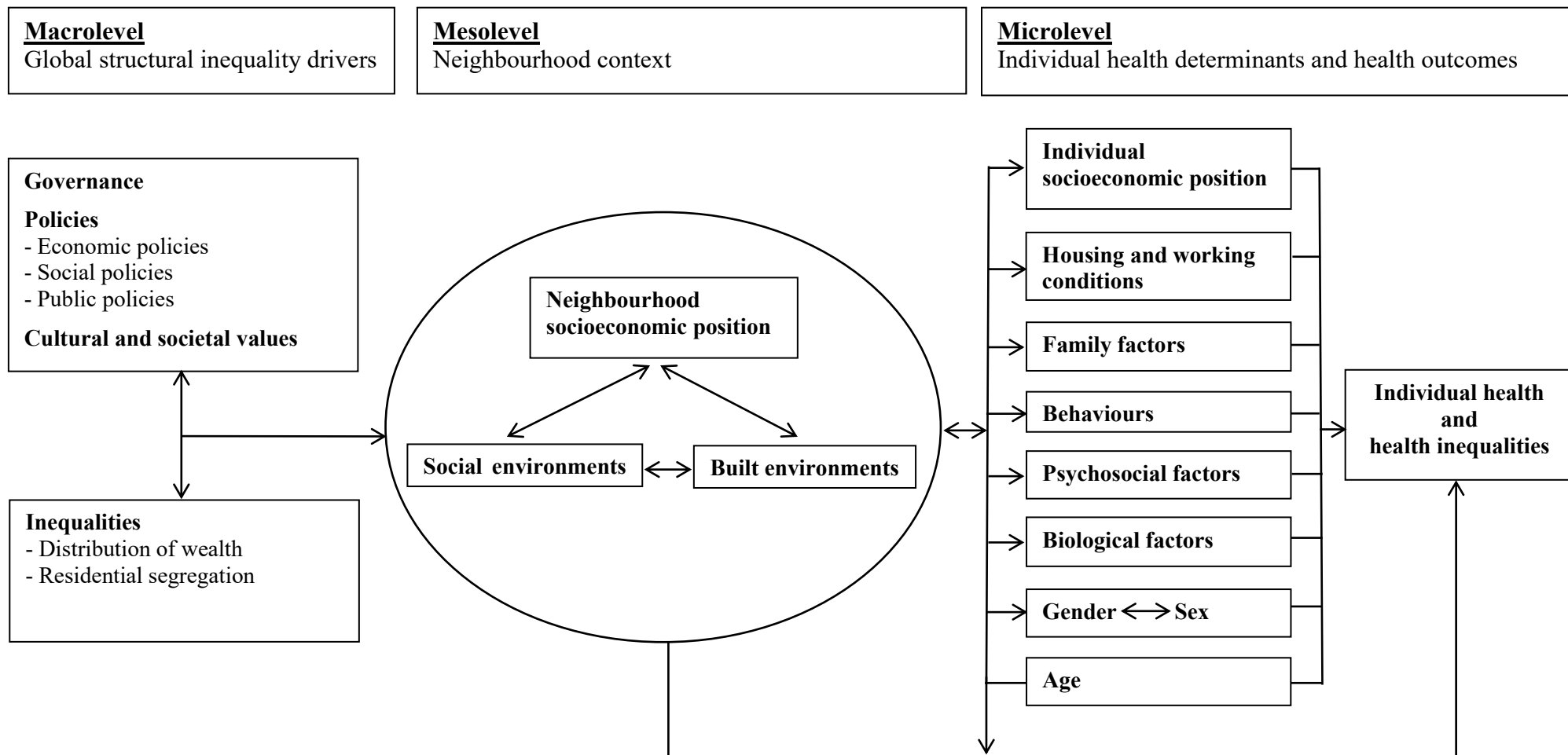
There is still an ongoing discussion in the literature to what extent socioeconomic area characteristics serve as a proxy for individual SEP. Various studies suggest that area size and the selection of socioeconomic indicators influence correlations between SEP on the area and individual level which may result in biased estimates in studies analysing socioeconomic inequalities in health (Geronimus & Bound, 1998; Pardo-Crespo et al., 2013; Soobader et al., 2001).

The microlevel contains individual health determinants and health outcomes. Individual SEP represents both vertical and horizontal characteristics describing SEP of individuals, such as income, education, ethnicity, or migration background. Housing and working conditions comprise indoor housing conditions and work-related environmental exposures. Family factors include all kind of factors describing family status, such as single parent, marital status, or family size. Behaviours contain all kind of health promoting and health threatening behaviours, such as physical activity, smoking, or alcohol consumption. Psychosocial stressors and resources, such as individual coping strategies, social support, job strain, or negative life events are a further important component on the microlevel. Genetic factors belong to the group of biological factors. The social construct gender and the biological construct sex are introduced as interrelated factors into the model to take into account the

ongoing issue to enhance the integration of theoretical gender concepts into health research (Hammarstrom et al., 2014; Krieger, 2003; Springer et al., 2012).

Neighbourhood contextual factors may have indirect effects towards individual health outcomes through individual factors on the microlevel. Individual factors can further modify direct association between neighbourhood context and individual health.

Figure 2 Conceptual model describing multilevel pathways of neighbourhood health inequalities



2 Research objectives

2.1 Independent and interactive effects of socioeconomic and objective built environments on individual health

Both neighbourhood SEP and built environmental factors play a significant role for explaining health inequalities between neighbourhoods. However, there is still lack of a systematic overview to what extent both characteristics are simultaneously considered in multilevel neighbourhood studies. Therefore, the overall goal was to conduct a systematic review to identify multilevel epidemiological studies considering characteristics of neighbourhood SEP and the objectively assessed built environment simultaneously in order to disentangle their independent or interactive effects on individual health outcomes and health behaviours.

The primary research question was how characteristics of neighbourhood SEP and the objective built environment were associated with individual health outcomes or health-related behaviours if both dimensions were considered simultaneously in multilevel modelling. Secondly, the review summarized knowledge on interactions between neighbourhood SEP, the built environment, and individual factors.

2.2 Contextual neighbourhood effects on child overweight

In the field of multilevel neighbourhood studies there is still need for further research on the age group of young children because most studies looked at adolescents or adults. Previous studies analysing associations between contextual neighbourhood factors and child health were predominantly conducted in the USA. Moreover, only a minority of studies analysed how neighbourhood context was associated with measures of overweight in younger children while simultaneously taking into account relevant socioeconomic and parental factors on the individual level in order to disentangle their independent associations. Therefore, two multilevel analyses were performed with pooled cross-sectional data from the city of Munich to investigate how neighbourhood context was related to overweight in children and contributed to the variation of overweight between neighbourhoods. Both socioeconomic and built environmental factors were simultaneously analysed with individual characteristics from 18 selected primary school enrolment zones which served as a proxy for the close neighbourhood environment.

The main research objective of the first multilevel analysis was to investigate how the socioeconomic context of neighbourhoods was associated with overweight while simultaneously considering indicators of individual SEP as well as further individual risk factors.

The second multilevel analysis investigated how the objective and perceived built environment and neighbourhood SEP were associated with overweight. Indicators of individual SEP and further important risk factors for overweight were considered on the individual level. A further objective in both analyses was to quantify how much variance of overweight between neighbourhoods was explained by individual factors and how much was attributable to the neighbourhood context.

2.3 Environmental neighbourhood inequalities in urban contexts

A deeper understanding to what extent environmental resources and burdens are distributed by socioeconomic neighbourhood characteristics is a prerequisite to assess whether a socioeconomic unequal distribution of such environments enhances health inequalities within cities. Therefore, two ecological studies in Munich and Dortmund were conducted with a research focus on socioeconomically driven environmental inequalities.

The first study analysed a wider range of environmental inequalities in the city of Dortmund with a deeper focus on the development of city wide indicators which are important for stimulating healthy urban planning processes. Correlation analysis was applied in order to analyse associations between socioeconomic indicators and environmental burdens and resources on the level of 170 administrative neighbourhoods in order to identify hot spot areas and to target planning-related interventions.

The second study focused on the socioeconomic distribution of green space availability in the city of Munich on the level of 108 administrative neighbourhood districts. There is still a great heterogeneity across existing ecological studies how green space availability within and around a neighbourhood was defined and measured. Neighbourhoods often vary in their size and shape which may result in generating different catchment areas of green space availability. Moreover, when administrative boundaries are used to measure green space availability, these boundaries are fixed and are therefore not able to consider adjacent green spaces in nearby neighbourhoods. From a statistical point of view, positive environmental variables are often highly skewed which need to be adequately addressed when parametric modelling approaches are applied.

Therefore, this study followed two research objectives. Firstly, it investigated whether neighbourhood SEP was associated with green space availability applying generalized linear models with a log-gamma regression in order to consider the non-normal distribution of the response variable. The second research objective was to apply methods based on geographic information systems (GIS) to define various catchment areas of green space availability and to analyse whether variations in size and kind of these catchment areas influenced relationships between neighbourhood SEP and green space.

3 Data description

3.1 Health monitoring units in Munich

The health monitoring units (GME) are organized by the Bavarian Health and Food Safety Authority and started in 2004. Surveys were conducted in three rural and three urban districts of the federal state Bavaria in Germany. The main aims of the GME-surveys were to systematically monitor the health status of children between 5 and 7 years old and to acquire health relevant data with a particular focus on environmental burdens and resources influencing health outcomes of children (Bolte et al., 2008; Bolte et al., 2007).

Between 2004 and 2015 seven cross-sectional surveys and a cohort study were conducted (Dreger et al., 2015; Gürlich et al., 2016; Weber et al., 2016). Each survey had a particular focus on selected health relevant issues, such as environment and health, UV exposure, allergies, or child development. Across these surveys there were overarching data which were conducted repeatedly (Bolte et al., 2007; Gürlich et al., 2016; Weber et al., 2016).

For multilevel analyses, three consecutive cross-sectional surveys in the city of Munich, conducted between 2004 and 2007 with identical procedures concerning data collection, were considered. Based on the Munich poverty report from 2002 (Romaus & Weizel, 2004) a sample of primary school enrolment zones were selected where the surveys took place to adequately represent the socioeconomic range of families within Munich.

The purpose of the multilevel analyses was to use these school enrolment zones as a proxy for the close neighbourhood environment. Contextual neighbourhood characteristics concerning the socioeconomic and built environment were included based on the geographic information of school districts where the children came from (see chapter 3.2).

18 school zones were identical in the three surveys which could be therefore combined and pooled for multilevel analysis. Four school zones were a priori excluded because each zone

contained only one observation. The final dataset contained 3499 children for whom data for BMI calculation were fully available. Each school zones included between 117 and 331 children. There were no remarkable differences concerning the sample size between the three surveys (see table 1).

Table 1 Number of observations per survey

Survey	Number of observations (n = 3499)
Survey 1	1068
Survey 2	1159
Survey 3	1272

Individual data on weight and height were objectively measured by trained staff. Further individual characteristics of socioeconomic family factors, parental and child risk factors for overweight, and perception of the close neighbourhood environment were derived from parental questionnaires. A detailed description of all individual data and derived variables from the parental questionnaires are listed in the two published papers (Schüle, Fromme, et al., 2016; Schüle, von Kries, et al., 2016).

3.2 Socioeconomic and environmental neighbourhood data from the city of Munich

Socioeconomic data from 18 selected primary school enrolment zones

For the two multilevel analyses five socioeconomic aggregated variables on the level of 18 school districts were considered to calculate an index describing neighbourhood SEP applying PCA. Averages from the years 2006 and 2007 were calculated (see table 2). Data on residential population were obtained from the city council of Munich. Household data on education were provided by microm GmbH, Neuss, Germany.

Table 2 Socioeconomic characteristics of selected school districts in the city of Munich (2006/07)

Neighbourhood socioeconomic variables on the school district level (N = 18)	Mean	Min	Max
Percentage of residents with no German citizenship	23.16	13.98	31.89
Percentage of residents with a German citizenship and a migration background	12.23	9.30	20.50
Percentage of households with lower education	29.65	20.50	38.20
Percentage of single parent households	3.48	2.11	4.72
Percentage of households with vocational training	38.80	33.35	42.85

Socioeconomic data from 108 administrative neighbourhood districts

For the ecological study in the city of Munich eight socioeconomic neighbourhood variables from 108 administrative neighbourhood districts were considered for index development describing neighbourhood SEP applying PCA, too. From the city council of Munich data on unemployment, German citizenship, migration history, and population density were provided. Population density was considered as an adjustment variable in multivariate analysis. Data on education and occupation were provided by microm GmbH, too. All data were available for the years 2011-2013 (see table 3). From these three years the average value was calculated and used for PCA.

Table 3 Socioeconomic neighbourhood characteristics in the city of Munich (2011-2013)

Socioeconomic variables from neighbourhood districts (N = 108)	Mean	Min	Max
Percentage of people in the age group 15-65 years receiving unemployment benefit part II	4.59	0.5	14.73
Percentage of unemployed people in the age group 15-65 years receiving social security under Hartz IV	3.36	0.77	6.7
Percentage of people in the age group below 15 years receiving social assistance	10.17	0	25.77
Percentage of residents with no German citizenship	24.76	11.93	71.77
Percentage of residents with a German citizenship and a migration background	38.18	22.87	77.73
Percentage of households with lower education	26.33	18.47	38.26
Percentage of households with no graduation	65.00	52.08	82.74
Percentage of households with vocational training	39.41	35.46	46.71

Population weighted playground and park availability on the level of 18 primary school enrolment zones

Data on public playgrounds and parks were provided by the city council of Munich. Data on playgrounds included available space for different age groups additionally. Each playground was categorized into the amount of space for infants (0-5 years), children (5-11 years), or youths (12-15 years). For multilevel analysis total playground space for infants and children within each school zone was calculated because these age groups were in accordance to the study population. Park space was intersected with the 18 school zones and the amount of square meters was calculated.

To take into account population characteristics within each school district, the amount of available square meters of playground space for children aged 0-11 years was weighted with the number of residents aged 0-11 years. For park space all residents within each school district were considered for weighting. Age-specific population data from 2004-2007 provided by the city council of Munich were averaged and used for population scaling. Finally, the population scaled playground and park variables were each categorized into tertiles (high, middle, and low). The variables are described in detail in one published multilevel analysis (Schüle, Fromme, et al., 2016).

Neighbourhood public greenspace availability based on 108 administrative neighbourhood districts in the city of Munich

For investigating relations between neighbourhood SEP and environmental resources, spatial data on various land use types including public green space were obtained from the city council of Munich. Public urban green space included land use types of public parks and public urban forests (deciduous forests, coniferous forests and mixed forests).

Five buffers in steps of 200 m (from 200 m up to 1000 m) were generated around each of the 108 administrative neighbourhood boundaries. Additionally, five different radii on the range between one and three kilometres (1000 m, 1500 m, 2000 m, 2500 m, and 3000 m) were considered around the neighbourhood centroid. For each catchment area the percentage of available green space was calculated. A detailed description of the method applied and a descriptive map are given in the published study (Schüle et al., 2017).

3.3 Socioeconomic and environmental neighbourhood data from the city of Dortmund

Socioeconomic data from 170 neighbourhoods in the city of Dortmund

For analysing environmental inequalities on the neighbourhood level with a focus on healthy urban planning, various socioeconomic data from 170 neighbourhoods were considered (see table 4). Data were from 2013 and 2014 and were provided by the city of Dortmund.

Table 4 Socioeconomic neighbourhood characteristics in the city of Dortmund (2013/14)

Socioeconomic neighbourhood variables (N = 170)	Mean	Min	Max
Percentage of people in the age group 18-65 receiving unemployment benefits (2013)	13.84	0	45.21
Percentage of resident having a migration background (2013)	26.21	2.70	76.62
Percentage of residents younger than 15 and older than 65 receiving social welfare aids (2014)	1.50	0	10.63
Percentage of residents receiving either unemployment benefits or social welfare aids (socioeconomic disadvantage) (2013)	10.38	0	36.57

Aggregated environmental neighbourhood data of noise and air pollution

Environmental data were provided by the city of Dortmund. Noise was calculated as a resulting noise burden from five noise sources (airport, tram, train, cars, and industry). Air quality in Dortmund was measured with nitrogen dioxide (NO₂) and particulate matter (PM₁₀). Green areas included parks and forest with a size greater than one hectare. Green areas around each neighbourhood were considered with a 400 m buffer around the neighbourhood boundaries. A detailed description of these environmental factors and the thresholds used for analysis is given in the published study (Flacke et al., 2016).

4 Applied Methods

4.1 Systematic review

The three databases PubMed, PsycINFO, and Web of Science were searched on the 5th of November 2013 to identify neighbourhood studies with a multilevel modelling approach considering both socioeconomic and built environmental factors and analysing their influence on individual health outcomes and health-related behaviours. In PubMed search terms of Medical Subject Headings were additionally considered.

Title and abstracts were screened by two reviewers independently with predefined inclusion criteria. A third reviewer was consulted if there was disagreement. If one of the inclusion criteria could not be clearly identified in the abstract, the full text of the record was analysed for eligibility by one reviewer. The search terms of all three databases and the applied inclusion criteria are shown in the published paper in detail (Schüle & Bolte, 2015).

An explicit search on grey literature was not performed because the review focused on observational epidemiological studies applying advanced statistical modelling which are most likely to be found in scientific journals. However, to take into account potential publication bias, the search strategy was not restricted to papers published in peer-reviewed journals. References of finally included records were additionally checked. As neighbourhood studies applying a multilevel modelling approach are a relatively recent study type, there were no restrictions to a specific time period.

In a qualitative analysis independent and interactive effects of the built environment and neighbourhood SEP towards individual health were visualized in four tables grouped by similar health outcomes or health-related behaviours. No quantitative assessment for risk of bias in individual studies was performed. However, in each study sample size, number of observations per neighbourhood, and total number of considered neighbourhood clusters were checked because simulation studies showed that small sample sizes in multilevel studies may result in biased effect estimates (Austin, 2010; Bell et al., 2010; Maas & Hox, 2005; Moineddin et al., 2007). The review was conducted in accordance to the PRISMA guidelines (Moher et al., 2009).

4.2 Contextual neighbourhood effects on child overweight

4.2.1 Principal component analysis

PCA was used as a statistical procedure for generating an index out of the variables describing neighbourhood SEP. It was applied for the eight aggregated socioeconomic characteristics from 108 neighbourhoods in the city of Munich and for the five aggregated socioeconomic characteristics from 18 primary school enrolment zones. It is an appropriate method for data reduction of correlated covariables and creates new uncorrelated variables, called principal components, which are linear combinations of the initial covariables (Tabachnick & Fidell, 2013). The first component had its largest eigenvalue, explained most of the variance, and was therefore used as an indicator for neighbourhood SEP. Higher values of the index implied a lower neighbourhood SEP. PCA was performed with the FACTOR procedure in SAS 9.3 (SAS Institute, 2013a)

4.2.2 Multilevel logistic regression

Multilevel logistic regression modelling was applied to correct for clustering of individuals within the same school district and to estimate variance between school districts separately from residual variation between individuals (J. Wang et al., 2012). The school enrolment zones were considered as level two units with random intercepts allowing the intercept estimates of each independent variable to vary among school zones.

All individual and contextual neighbourhood variables which were associated with overweight with a Wald's $P < 0.2$ in bivariate logistic regression were included in multivariate analysis (Hosmer et al., 2013). The variance inflation factor (VIF) ($VIF_i = 1/T_i$) was used to assess multicollinearity between the covariables. The VIF is calculated with the tolerance (T) ($T_i = 1 - R_i^2$). R_i^2 is the calculated variance of each covariable associated with all other independent variables. A VIF higher than 10 indicates a serious problem of multicollinearity (Alin, 2010; Harrell, 2001; Menard, 2002).

By comparing the covariance estimates between single multilevel models, it was assessed how much variance of overweight between neighbourhoods was explained by individual child and parental variables, perceived environmental exposures, housing characteristics, contextual neighbourhood SEP, age-specific public playground space, and park availability. All multilevel models were adjusted for the three survey years considering each survey as a dummy variable.

As area level variance parameter estimates in multilevel logistic regression are difficult to interpret because they are on the log odds scale (Larsen & Merlo, 2005), the proportional change in variance (PCV) in percent and the median odds ratio (MOR) according to the equations by Merlo et al. were calculated (Merlo et al., 2006; Merlo, Yang, et al., 2005). The PCV is calculated with the formula:

$$PCV = ((V_a - V_b)/V_a) \times 100$$

where V_a is the area level variance parameter estimate of the empty model and V_b is the area level variance parameter estimate including covariables.

The MOR is calculated with the formula:

$$MOR = \exp[\sqrt{(2 \times V_a)}] \times 0.6745$$

where V_a is the area level variance parameter estimate of each model. The MOR describes the increased risk in median when an individual would move to another area with higher risks when selecting two areas randomly. A MOR greater than one would indicate area level variations in the probability of being overweight and a MOR equal to one would mean no variation on the area level. The GLIMMIX procedure in SAS 9.3 was applied for multilevel model calculation (Ene et al., 2014; SAS Institute, 2013c).

In one multilevel analysis, considering the perceived built environment and objectively measured playground and park space in addition to neighbourhood SEP (Schüle, Fromme, et al., 2016), the Akaike Information Criterion (AIC) (Akaike, 1974) and the Bayesian Information Criterion (BIC) (Schwarz, 1978) were considered to measure the relative goodness of fit. Therefore, parameter estimation was based on maximum likelihood estimation with the Laplace method which approximates a marginal log likelihood. This method was selected to ensure unbiased model comparisons because of a true likelihood approximation (Schabenberger, 2007).

4.2.3 Multiple imputation of income data

Multiple imputation for the missing values of the categorical income variable was performed in order to check whether the parameter estimates of the independent variables change. However, multiple imputation of hierarchical data is still a research area with many open issues (Van Buuren, 2011). There is still no standard procedure on how multilevel data can be imputed and then adequately be analysed and pooled. For example, the MI procedure in SAS still ignores the clustering structure. One of the main challenges is to pool the estimates from

the variance components in order to obtain valid covariance parameter estimates. Pooling estimates is possible within the MIANALYZE procedure, however, there is still no method to pool covariance estimates from the random intercept part. Some macros were already developed in order to solve these issues (Mistler, 2013a, 2013b), however, they have limitations, too. For example, these macros are primarily applicable for continuous data and are not appropriate for ordinal variables.

The method of cumulative logistic regression imputation within the MI procedure in SAS 9.3 was applied which is appropriate for ordinal variables (Allison, 2005; Ault, 2012; Berglund, 2010; SAS Institute, 2013d). Within the MI procedure a two-step approach was performed. A monotone missing pattern was produced which is a precondition for performing multiple imputation of ordinal variables. The following variables were used to impute the categorical income variable: nationality of the child, parental education, parental working status, single parenthood, and crowding. To consider the clustered data structure, school zones were taken into account as dummy variables within the imputation procedure. The MIANALYZE procedure (SAS Institute, 2013e) was applied to generate valid standard errors, p-values, and 95 % confidence intervals (CIs) for the fixed effects and to combine the results of the multilevel analyses performed with the GLIMMIX procedure (SAS Institute, 2013c).

4.3 Environmental neighbourhood inequalities

4.3.1 Generalized linear models (Munich)

Log-gamma regression belonging to the group of generalized linear models (GLMs) was applied for analysing associations between neighbourhood SEP and green space availability. GLMs hypothesize that the response variable follows a selected probability distribution of the exponential family. A general link function links the expected mean of the response variable to the linear predictor. In contrast to linear regression where a normal distribution of the response variable is assumed, which is often achieved by transforming the original data, GLMs have the advantage that the link function achieves linearity separated from the distribution of the response variable. As a result, non-normal response data can be predicted linearly and it is possible to make inferences about arithmetic means while keeping their original scale which makes interpretations of parameter estimates much easier. The gamma distribution was chosen as a hypothesized response distribution because it is suitable for modelling positive continuous response variables resulting in left-skewed distributions which is the case for the green space variables (Fox, 2016). The logarithmic function was selected as

the link function which assumes a multiplicative effect on the outcome by the selected predictor variables. By exponentiating the coefficients, the linear predictor can be interpreted as the factor by which the arithmetic mean of the outcome is multiplied. The GENMOD procedure was applied in SAS 9.3 for model calculation (SAS Institute, 2013b).

4.3.2 Correlation analysis (Dortmund)

Spearman rank correlation coefficients (Spearman, 2010) between the four socioeconomic neighbourhood variables were calculated in order to identify an indicator describing neighbourhood SEP for the 170 neighbourhoods in the city of Dortmund. Relationships between neighbourhood SEP and environmental variables were analysed on a continuous scale with spearman rank correlation coefficients, too, because of a non-normal distribution of the data.

Quartiles of neighbourhood socioeconomic variables and environmental variables were generated in order to analyse associations between categorical socioeconomic and environmental neighbourhood variables with chi-squared tests (Agresti, 2013). For mapping cumulative environmental burdens, environmental variables were categorized in quartiles from 1 (low) to 4 (very high).

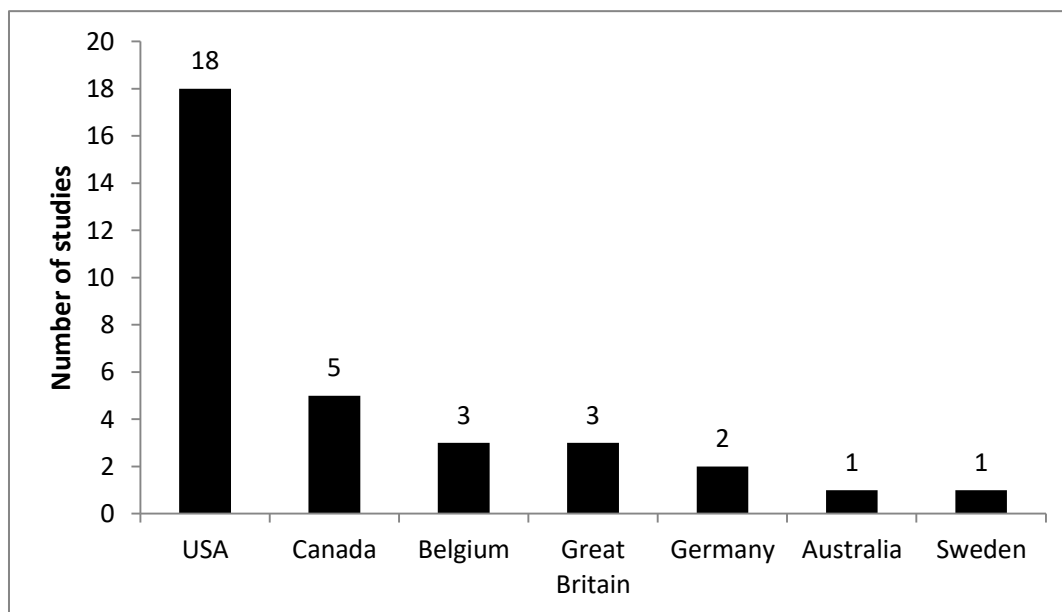
5 Summary of results

5.1 Evidence on independent and interactive health effects of neighbourhood contexts

The following figures and tables summarize the results from the systematic review on multilevel studies investigating both neighbourhood SEP and built environmental factors towards individual health outcomes or health-related behaviours. A detailed qualitative analysis of associations found in the reviewed studies is shown in the result section in the published paper (Schüle & Bolte, 2015).

After abstract screening, full text analysis, and check of references 33 studies were considered for qualitative analysis. Except of one study, all had a cross-sectional study design and 18 of them were conducted in the United States. Only two studies were identified from Germany (see figure 3). Most studies examined an adult population sample.

Figure 3 Number of studies identified by country



Seven studies investigated exclusively outcomes measuring various forms of physical activity (see figure 4). Five of these seven studies analysed an adult population sample (Owen et al., 2007; Sundquist et al., 2011; Van Dyck, Cardon, Deforche, Owen, et al., 2010; Van Dyck, Cardon, Deforche, Sallis, et al., 2010; Ming Wen & Zhang, 2009), one adolescents (De Meester et al., 2012), and one study focused on people ≥ 45 years old (Riva et al., 2009).

Six studies examined measures indicating overweight or obesity either directly with the BMI as a continuous variable or with BMI thresholds for overweight or obesity (Grafova et al.,

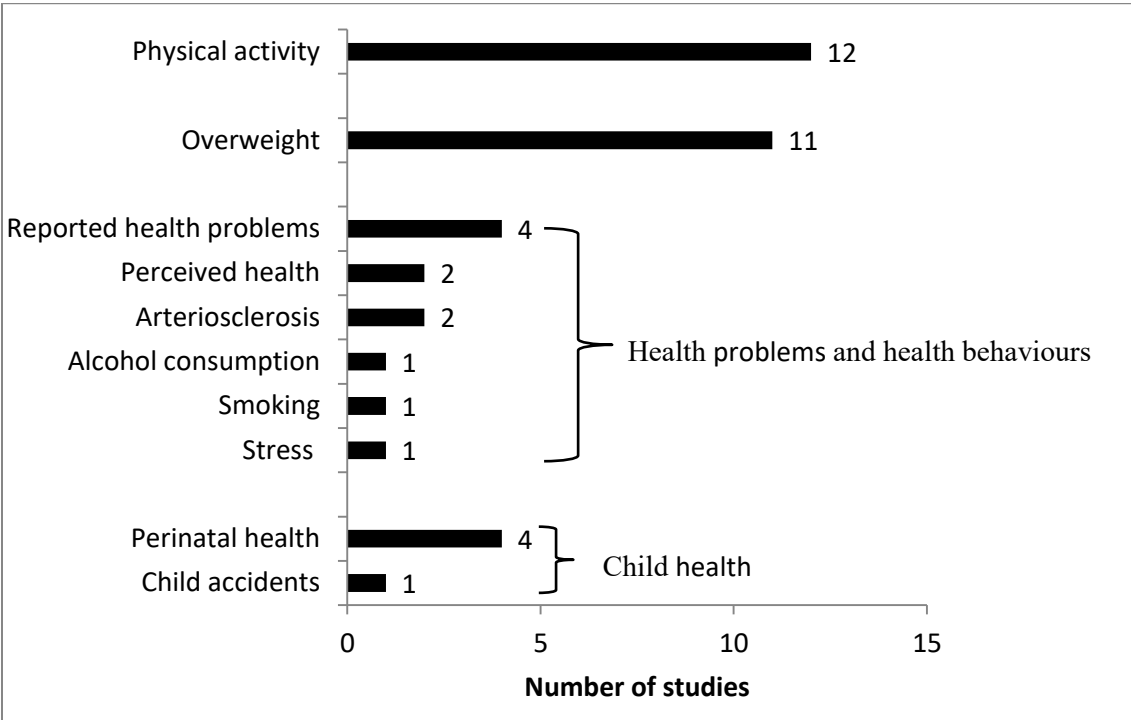
2008; Inagami et al., 2009; K. Moore et al., 2013; Ross et al., 2007; M. C. Wang et al., 2007; M. Wen & Kowaleski-Jones, 2012). One of these six studies considered people 45-84 years old (K. Moore et al., 2013), and one analysed a study population ≥ 55 years old (Grafova et al., 2008). The other four studies considered an adult population sample.

Five studies analysed both measures of physical activity and overweight (Stephanie A. Prince et al., 2012; S. A. Prince et al., 2011; Sallis et al., 2009; Scott et al., 2009; Slater et al., 2010) including one study which considered mental and physical quality of life, and depressive symptoms additionally (Sallis et al., 2009). All studies looked at adults, except of one study which focused on students 13-16 years old (Slater et al., 2010).

Four studies investigated how neighbourhood context was associated with perinatal health outcomes (Genereux et al., 2008; Ponce et al., 2005; Williams et al., 2007; Zeka et al., 2008). One study had a longitudinal study design focusing on accidents and injuries in children 0-5 years old (Reading et al., 2008).

Five studies analysed self-rated health or self-reported health problems (Cummins et al., 2005; Freedman et al., 2011; Freedman et al., 2008; Matthews & Yang, 2010; Stafford et al., 2005). One study focused exclusively on stress (Yang & Matthews, 2010), one on smoking (Chuang et al., 2005), one on heavy alcohol consumption (Pollack et al., 2005), and two on objectively measured coronary artery calcification (Dragano, Hoffmann, Moebus, et al., 2009; Dragano, Hoffmann, Stang, et al., 2009). Four of these five studies looked at older adults, two included people ≥ 55 years old (Freedman et al., 2011; Freedman et al., 2008) and two considered people 45-75 years old (Dragano, Hoffmann, Moebus, et al., 2009; Dragano, Hoffmann, Stang, et al., 2009).

Figure 4 Number of studies identified by health outcomes and health behaviours



Sixteen studies calculated an index capturing various socioeconomic characteristics of the neighbourhood population describing neighbourhood SEP (Chuang et al., 2005; Cummins et al., 2005; Freedman et al., 2011; Freedman et al., 2008; Grafova et al., 2008; Inagami et al., 2009; Matthews & Yang, 2010; K. Moore et al., 2013; Pollack et al., 2005; Stephanie A. Prince et al., 2012; S. A. Prince et al., 2011; Scott et al., 2009; Stafford et al., 2005; M. C. Wang et al., 2007; M. Wen & Kowaleski-Jones, 2012; Ming Wen & Zhang, 2009; Yang & Matthews, 2010). The others used single indicators of neighbourhood SEP, such as measures of income, education, poverty, or unemployment.

The objective built environment was described with a variety of measures. Indices for walkability, land use mix, and urbanity were mostly used. Single land use types were also considered, such as retail, recreational areas, restaurants, fast food outlets, cultural and education institutions, or health and human services. Environmental pollution, such as from traffic or waste sites, was mainly investigated in studies focusing on perinatal health, mental health, or self-rated health. Eleven studies measured built environmental exposures on the individual level (Chuang et al., 2005; Dragano, Hoffmann, Moebus, et al., 2009; Dragano, Hoffmann, Stang, et al., 2009; Genereux et al., 2008; K. Moore et al., 2013; Pollack et al., 2005; Ponce et al., 2005; Scott et al., 2009; M. C. Wang et al., 2007; Williams et al., 2007; Zeka et al., 2008).

Tables 5-8 show associations and interactions of socioeconomic and built environmental factors sorted by analysed outcomes. The tables represent counted number of associations and do not include any qualitative assessment, such as after strengths of associations or sample size. A significant relationship in the final multilevel model, defined with a p-value <0.05 or a 95 % CI not including one, was counted as an independent association. The columns with interactions comprise associations which were only significant for one specific characteristic in stratified analysis, significant associations in stratified analyses and differences in the parameter estimates, or significant interaction terms. The columns “No associations” include reported parameter estimates with p-values >0.05 or 95 % CIs including one.

Eleven positive associations between objectively measured walkability and individual physical activity independent of neighbourhood SEP and individual factors were identified. Most multilevel studies did not find a significant association between neighbourhood SEP and physical activity measures. There was also a trend that the availability of sport facilities was not associated with individual physical activity. Noise and air pollution, public institutions, and public transport were not significantly associated with physical activity (see table 5).

Table 5 Number of associations between neighbourhood contexts and physical activity

Contextual factors	Independent associations ¹⁾	Interactions ²⁾	No associations ³⁾
Neighbourhood socioeconomic position	4	2	23
Built environment			
Noise and air pollution	-	-	3
Open and green space	-	2	4
Walkability	11	5	7
Public institutions	-	-	2
Sport facilities	1	-	6
Retail	-	2	1
Density (buildings and residents)	1	-	2
Restaurants (fast food included)	2	1	4
Land use mix indices	2	-	3
Public transport	-	-	2
Total built environment	17	10	34
¹⁾ Significant relationships with p-values <0.05 in the final multilevel model or 95 % CIs not including one			
²⁾ Significant associations of one specific characteristic in stratified analysis, significant associations in stratified analyses and differences in the parameter estimates, or significant interaction terms			
³⁾ Associations with p-values >0.05 or 95 % CIs including one			

Eleven independent relationships between neighbourhood SEP and measures of overweight were identified (see table 6). A low neighbourhood SEP was associated with outcomes for overweight or obesity. Identified associations between built environmental factors and overweight were mixed and both significant and non-significant associations were found for most factors.

Table 6 Number of associations between neighbourhood contexts and overweight

Contextual factors	Independent associations ¹⁾	Interactions ²⁾	No associations ³⁾
Neighbourhood socioeconomic position	11	2	5
Built environment			
Noise and air pollution	-	1	3
Open and green space	1	3	2
Walkability	4	1	6
Sport facilities	1	1	1
Retail	-	4	2
Density (buildings and residents)	-	-	3
Restaurants (fast food included)	2	2	3
Total built environment	8	12	20
¹⁾ Significant relationships with p-values <0.05 in the final multilevel model or 95 % CIs not including one ²⁾ Significant associations of one specific characteristic in stratified analysis, significant associations in stratified analyses and differences in the parameter estimates, or significant interaction terms ³⁾ Associations with p-values >0.05 or 95 % CIs including one			

For further health problems and health behaviours results on associations of neighbourhood SEP were mixed and significant associations, no associations, and interactions were approximately balanced (see table 7). Also for noise and air pollution mixed results were found across studies. For walkability most studies did not find significant associations, and also for sport facilities and density measures no associations were identified.

Table 7 Number of associations between neighbourhood contexts and health problems and health behaviours

Contextual factors	Independent associations ¹⁾	Interactions ²⁾	No associations ³⁾
Neighbourhood socioeconomic position	6	6	10
Built environment			
Noise and air pollution	3	2	5
Walkability	2	-	6
Public institutions	-	2	2
Sport facilities	-	-	2
Retail	-	4	2
Density (buildings and residents)	-	-	5
Empty buildings	-	2	-
Total built environment	5	10	22
¹⁾ Significant relationships with p-values <0.05 in the final multilevel model or 95 % CIs not including one ²⁾ Significant associations of one specific characteristic in stratified analysis, significant associations in stratified analyses and differences in the parameter estimates, or significant interaction terms ³⁾ Associations with p-values >0.05 or 95 % CIs including one			

For perinatal and child health associations of neighbourhood SEP were also mixed. Regarding the built environment, mostly traffic-related measures were analysed and most studies identified significant interactions (see table 8). Measures of noise and air pollution mostly interacted with characteristics describing individual or neighbourhood SEP. However, no systematic findings were found across studies on how neighbourhood SEP or individual SEP influenced relationships between measures of air and noise pollution and infant health.

Table 8 Number of associations between neighbourhood contexts and child health

Contextual factors	Independent associations ¹⁾	Interactions ²⁾	No associations ³⁾
Neighbourhood socioeconomic position	2	1	2
Built environment			
Noise and air pollution	1	7	7
Open and green space	-	1	2
Building characteristics	-	-	1
Total built environment	1	8	10
¹⁾ Significant relationships with p-values <0.05 in the final multilevel model or 95 % CIs not including one ²⁾ Significant associations of one specific characteristic in stratified analysis, significant associations in stratified analyses and differences in the parameter estimates, or significant interaction terms ³⁾ Associations with p-values >0.05 or 95 % CIs including one			

To summarize, there was a great heterogeneity across studies concerning study designs, reporting of multilevel results, and defined measures of neighbourhood SEP and built environments which made quantitative analysis not possible. This systematic review found out that most consistent relationships were found between built environmental factors and physical activity outcomes. Studies which investigated associations between neighbourhood context and overweight found most consistent associations for factors describing neighbourhood SEP. Although interactive effects between neighbourhood contextual factors and individual characteristics were present across all analysed outcomes, no systematic patterns of modifying factors could be identified.

5.2 Neighbourhood context and overweight in children

Neighbourhood SEP, individual SEP, and overweight

In the final multilevel model low or middle parental education and non-German nationality of the child were positively associated with children's overweight. All other characteristics describing individual SEP remained not significant. Furthermore, a low neighbourhood SEP was positively associated with overweight independent from individual factors.

The full model including neighbourhood SEP explained additional 19.1 % between neighbourhood variance of overweight. However, the neighbourhood intercept variance estimates from which the PCV was calculated showed wide CIs. The sensitivity analysis with multiple imputed data for missing values on household income revealed similar estimates for individual variables and contextual neighbourhood SEP. All results are described in detail in the published paper (Schüle, von Kries, et al., 2016).

This multilevel analysis showed that individual determinants explained most of the between neighbourhood variance of overweight in children. The socioeconomic context was associated with overweight independently from individual overweight determinants and additionally explained differences in overweight between neighbourhoods suggesting underlying pathways of built or social environments influencing overweight in children.

Neighbourhood SEP, built environmental factors, and overweight. Disentangling individual and contextual relationships

The first multilevel null model with no covariables had a MOR of 1.32 indicating area level variations for individual probability of being overweight. In the second model including individual child and parental factors, a high birth weight, parental overweight and obesity, and

low or middle parental education were positively associated with children's overweight. In the third model perceived built environmental exposures and housing characteristics were additionally considered. Only living in a multiple dwelling was positively related with overweight.

In the final model, taking individual and contextual characteristics into account, neighbourhood SEP, age-specific playground space, and public park availability were not independently associated with overweight. All variables which were significantly associated with overweight in the second and third model remained significant.

Comparing the PCV between the four models, individual parental and child factors explained 66.8 % of the area level variance. In the third model perceived parental built environmental exposures and housing characteristics explained 21.4 % additionally. In the final model the covariance parameter estimate from random intercepts was zero. As a result, no differences on the area level concerning probabilities of being overweight existed in the final model, and neighbourhood SEP and playground and park space explained the remaining 11.8 % of area level variance. All results are described in detail in the published paper (Schüle, Fromme, et al., 2016).

This multilevel analysis showed that individual child and family factors played the most important role for overweight in children. Both perceived and objective measures of the built environment, and the socioeconomic neighbourhood context played a subordinate role because most characteristics were not associated with overweight and explained less variation of overweight differences between neighbourhoods than individual determinants.

5.3 Environmental inequalities on the neighbourhood level

Based on spearman rank correlation coefficients between the four aggregated neighbourhood socioeconomic variables the combined variable describing percentage of residents receiving either unemployment benefits or social welfare aids (socioeconomic disadvantage) was used as an indicator describing neighbourhood SEP in the city of Dortmund. This variable correlated most strongly with the other socioeconomic neighbourhood factors.

Spearman rank correlation coefficients and chi square tests further showed that neighbourhood socioeconomic disadvantage was significantly negatively correlated with green space availability and significantly positively correlated with NO₂ and PM₁₀. Higher values of the variable describing neighbourhood disadvantage imply a higher degree of

socioeconomic deprivation. There was no significant correlation between neighbourhood socioeconomic disadvantage and noise pollution. Results of the statistical tests, descriptive maps showing the spatial distribution of socioeconomic environmental disparities, and identified hot spots are provided in the published paper (Flacke et al., 2016).

This case study showed that both socioeconomic and environmental indicators available on administrative small areas provided a good starting point for analysing environmental inequalities in an urban context. The identification and mapping of hot spots facing multiple environmental burdens were a good precondition for urban planning interventions.

5.4 Socioeconomic disparities of neighbourhood public green space

Multivariate associations between neighbourhood SEP and green space availability with different neighbourhood buffers in the city of Munich

In multivariate log-gamma regression a lower neighbourhood SEP was associated with decreasing neighbourhood green space availability. For example, with one standard deviation increase of the neighbourhood SEP index on a continuous scale there was on average 21 % less green space available within a neighbourhood including a 200 m buffer around the boundaries additionally. When categories of neighbourhood SEP were analysed, neighbourhoods with a low SEP had on average 43 % less green space available including a 200 m buffer than neighbourhoods with a high SEP.

Multivariate associations between neighbourhood SEP and green space availability measured from neighbourhood centroids with different radii in the city of Munich

A low neighbourhood SEP was also associated with decreasing neighbourhood green space availability based on catchment areas measured from neighbourhood centroids with different radii. In both continuous and categorical models a lower neighbourhood SEP was significantly related with decreasing availability of green space. With an increasing radius there was a decrease of the strength of the association. On a continuous scale with one standard deviation increase of the neighbourhood SEP index there was on average 27 % less green space available for the 1000 m radius. For the 3000 m radius with one standard deviation increase of the neighbourhood SEP index there was on average 9 % less green space available. This trend was similar for the categorical models. For the 1000 m radius neighbourhoods with a low SEP had on average 52 % less green space available than neighbourhoods with a high neighbourhood SEP, whereas for the 3000 m radius low SEP

neighbourhoods had on average 21 % less green space available than neighbourhoods with a high SEP.

This case study in Munich showed that both geographic methods for defining catchment areas of green space availability on the neighbourhood level revealed evidence on disproportional distributions of public green space by neighbourhood deprivation.

6 Discussion and critical reflexions of methods and results

6.1 Evidence on pathways between neighbourhood contexts and individual health

In a systematic review it was analysed how characteristics of neighbourhood SEP and the objective built environment were associated with individual health outcomes or health-related behaviours if both dimensions were considered simultaneously in multilevel modelling. A further focus was to look at interactions between neighbourhood SEP, the built environment, and individual factors, such as individual SEP.

Outcomes of physical activity and overweight were the most frequent analysed outcomes. In many multilevel studies a low neighbourhood SEP was independently associated with overweight or obesity. In contrast, studies investigating outcomes of physical activity found mostly no independent relationships with neighbourhood SEP.

Many studies showed an independent relation of neighbourhood SEP with individual overweight while simultaneously adjusted for built environmental and individual factors (Grafova et al., 2008; Inagami et al., 2009; K. Moore et al., 2013; Ross et al., 2007; Sallis et al., 2009; Slater et al., 2010; M. C. Wang et al., 2007; M. Wen & Kowaleski-Jones, 2012). Although the effect of neighbourhood SEP on overweight measures was small in most final multilevel models, this systematic trend suggests different underlying causal pathways between neighbourhood SEP and overweight than for physical activity where no clear systematic independent relationships for neighbourhood SEP were found. Referring to the proposed conceptual model in chapter 1.5 associations between neighbourhood SEP and overweight could be attributed to omitted individual or contextual characteristics from the built or social environment which explain independent relations between a low neighbourhood SEP and individual overweight.

There were mostly mixed results on associations between built environmental factors and overweight, physical activity, health problems and behaviours, and child health. For physical activity measures most consistent results were found for walkability indicators in the neighbourhood environment. Studies showed that a higher walkability index was associated with higher moderate-to-vigorous physical activity or increased walking behaviours independent of neighbourhood SEP and individual factors (Sallis et al., 2009; Sundquist et al., 2011; Van Dyck, Cardon, Deforche, Sallis, et al., 2010). The walkability index was the only comparable built environmental factor across studies. It is a composite index which combines

different urban forms of the built environment which are relevant for people being active. The four main components being represented in the index are residential density, data on retail areas, intersection density, and land use mix indices (Lawrence D. Frank et al., 2006; L. D. Frank et al., 2010). This systematic finding suggests a direct effect of objectively measured built environmental factors improving walkability on individual physical activity independent of socioeconomic characteristics of individuals or neighbourhoods.

Most studies reported results from their final multilevel model, where estimates were mutually adjusted for neighbourhood and individual factors. Therefore, no systematic comparison of multilevel models which analyse only the contextual influence of neighbourhood SEP, and which consider both neighbourhood SEP and the built environment, all adjusting for the same individual characteristics, was possible. Such a comparison would give a better understanding to what extent built environmental factors explain independent associations between neighbourhood SEP and individual health.

For most built environmental factors there was limited comparability. The majority of all studies calculated weighted numbers of various facilities, such as stores, sport and recreational facilities, parks, or restaurants. There was a great variety concerning the weights that were used. Weights being most often used were fixed number of residents, number of neighbourhood residents, neighbourhood size, or square kilometre. Moreover, many studies calculated indices, mostly derived from factor analysis. The number and kind of built environmental variables contained in these scores was too heterogeneous for drawing comparisons. A minority of studies calculated distance based measures, such as to main roads, stores, or parks. Distances were calculated either from individual home addresses or from neighbourhood centroids.

The great heterogeneity of metrics and definitions being used for calculating built and also socioeconomic neighbourhood variables may further explain mixed results. A study from Montréal investigated whether different aggregation and distance methods to measure the accessibility of health care services in the neighbourhood may lead to different results. Results showed that various distance based methods are strongly correlated, however, for different aggregation methods errors were observed which could lead to imprecise estimates in studies investigating neighbourhood health effects (Apparicio et al., 2008). The limited comparability across studies which investigated contextual neighbourhood effects is consistent with previous systematic reviews, which focused either on a specific health

outcome or exclusively on one neighbourhood environmental dimension (Ding et al., 2011; Feng et al., 2010b; Mair et al., 2008; Metcalfe et al., 2011).

The systematic review showed mixed and partially contrasting results on interactions between neighbourhood SEP, built environments, and individual factors. Sex, ethnicity, or individual SEP often modified associations between neighbourhood SEP or the objective built environment and individual health.

One study observed an impact of a health promoting built environment only in neighbourhoods with a low SEP (De Meester et al., 2012). On the other hand there were studies demonstrating that associations between a higher built environmental burden and poor health or negative health behaviours were only significant or stronger in neighbourhoods with a high SEP (Chuang et al., 2005; Genereux et al., 2008). Furthermore, there were characteristics of the built environment and neighbourhood SEP from which only women's or men's health or health-related behaviours benefited or suffered (Dragano, Hoffmann, Moebus, et al., 2009; Dragano, Hoffmann, Stang, et al., 2009; Freedman et al., 2011; Freedman et al., 2008; Grafova et al., 2008; Stephanie A. Prince et al., 2012; S. A. Prince et al., 2011; Stafford et al., 2005; M. C. Wang et al., 2007). However, no systematic findings which specific factors of neighbourhood SEP or the built environment have stronger effects to men's or woman's health were found across studies.

Therefore, this review suggests that aspects of sex/gender differences towards associations between socioeconomic and neighbourhood built environments and health need further investigations. Local specific social policies, or shared social norms and values may further contribute to sex/gender specific differences towards contextual neighbourhood exposures and neighbourhood perceptions. Moreover, there is still need for further research how SEP characteristics, both on the neighbourhood and individual level, modify associations between built environments and health and which underlying pathways explain these interactions. As introduced in chapter 1.3 and in the proposed conceptual model in chapter 1.5, psychosocial mechanisms, such as contextual induced psychosocial stress or benefits, should be considered when aspects of socioeconomic vulnerability are investigated.

Limitations and strengths

The main strength of this review is that there was an exclusive focus on multilevel studies which considered both characteristics of neighbourhood SEP and the objective built environment simultaneously. This offered a detailed summary of independent relations to

individual health outcomes and behaviours and interactions between these two environmental dimensions and individual factors. The systematic consideration of interactions on the neighbourhood and the individual level revealed new insight which role these dimensions play in epidemiological neighbourhood research and identified where further research is needed. A further strength is that the systematic search was not restricted to specific health outcomes or age and population groups. As a result, it was possible to identify for which health outcomes, health-related behaviours, or population groups evidence is lacking and further research is necessary.

A first limitation of this systematic review is that the qualitative analysis only visualized significance or non-significance and direction of associations or interactions and did not make any comparisons on strength of the associations. A second limitation is that only titles and abstracts were screened with the developed search code. Besides that, the Medical Subject Headings used in the PubMed database may not correspond to selected keywords by authors. Therefore, the search strategy was maybe not sensitive enough and could not identify all relevant studies. To reduce this limitation, all references of included studies were checked. A separate search in sources of grey literature was not performed. However, we could not identify relevant grey literature which was cited in included studies.

Recommendations for future multilevel research

Based on this review the following recommendations for future research in the field of multilevel neighbourhood studies are given. For getting a deeper understanding of causal pathways between neighbourhood context and individual health the consideration of built or social environmental factors as mediating variables would contribute to a deeper theoretical understanding of neighbourhood health inequalities. Innovative methods from the field of mediation analysis can be applied for different study designs including also a multilevel data structure (Krull & MacKinnon, 2001; MacKinnon et al., 2007).

Furthermore, conceptual models from the scientific field of risk assessment with a specific focus on different forms of vulnerability and cumulative environmental exposures on the individual and neighbourhood level may provide a good theoretical basis to identify relevant vulnerability factors. Such conceptual models provide a good starting point to differentiate between various stressors coming from the built environmental, such as noise pollution, or which can be identified on the individual level, such as psychosocial stress or a low individual SEP (deFur et al., 2007; Levy, 2008).

The review detected that sex/gender specific differences in associations between built and socioeconomic neighbourhood environments and individual health outcomes and behaviours exist. Therefore, integrating gender theoretical concepts and intensifying gender related discussions in epidemiological neighbourhood health studies is highly recommended (Hammarstrom et al., 2014; Krieger, 2003).

There is a need to adhere to guidelines on how results from multilevel modelling should be reported. One key feature of multilevel models is that they are able to sort out variance components both on the neighbourhood and individual level which provide important information how individual health varies between and within neighbourhoods, and how much of these variance can be explained by contextual factors. Existing glossaries and tutorials about multilevel modelling which support a better reporting of multilevel results should therefore receive more attention (Diez Roux, 2002; Merlo et al., 2006; Merlo, Chaix, et al., 2005).

In some studies it was not clear what kind of cross-level or within-level interactions were analysed. Therefore, researchers are encouraged to systematically report if and which cross-level or within-level interactions were analysed regardless of their statistical significance. Moreover, most studies did not provide descriptive statistics about sample sizes of individual observations per neighbourhood cluster which is important for assessing potential bias of effects or variance estimates. Publishing such statistical information would make quantitative comparisons of multilevel models across studies easier.

The review revealed a great heterogeneity of metrics and definitions of variables describing the built environment. The only and most consistent built environmental factor across studies was the walkability index. More of such standardized indices measuring the built environment would increase comparability across studies.

Finally, more studies considering both environmental dimensions are needed which focus on children, because they are more vulnerable to environmental burdens than other population groups (Tamburlini, 2002). Moreover, there is a lack of studies analysing how neighbourhood SEP and built environmental factors influence mental health outcomes, such as depression (Orban et al., 2016), or health-related risk behaviours, such as smoking or alcohol consumption.

6.2 Contextual neighbourhood effects on child overweight

The influence of both neighbourhood SEP and built environmental factors on overweight was analysed in two multilevel analyses with cross-sectional data on 3499 children from 18 school enrolment zones in the city of Munich. The first analysis considered a socioeconomic index derived from PCA describing neighbourhood SEP as a contextual neighbourhood variable. A low neighbourhood SEP was significantly associated with overweight while simultaneously considering important risk factors for children on the individual level which suggest underlying pathways of the built or social environment explaining relations between neighbourhood SEP and overweight.

Apart from neighbourhood SEP the second multilevel analysis considered population weighted built environmental variables of playground space and public park space as contextual variables on the neighbourhood level. Apart from relevant individual risk factors for child overweight, such as parental overweight or SEP, perceived environmental neighbourhood variables and housing characteristics were additionally considered on the individual level. Both contextual neighbourhood variables and perceived environmental variables were not significant in the final multilevel model. Only people living in a multiple dwelling had a significantly higher chance being overweight than people living in other house types.

Although neighbourhood SEP was independently associated with overweight in children in our first analysis, both studies showed that individual child and family factors played the more important role for overweight in young children. A high birth weight, parental overweight, and low parental education were significantly associated with overweight in the final multilevel model. However, both neighbourhood SEP and perceived and objective built environmental neighbourhood factors explained additional overweight variance between neighbourhoods.

Results of individual factors are in line with previous studies investigating most relevant individual risk factors for overweight in young children. A systematic review by Shrewsbury and Wardle identified that low parental education was the most consistent socioeconomic indicator which was associated with overweight in childhood (Shrewsbury & Wardle, 2008). Other studies from Germany are also in line with our result: The German Health Interview and Examination Survey for children and adolescents (KiGGS) identified parental overweight and a low SEP, measured with parents' income, education, and occupational status, as the

strongest predictors for overweight (Kleiser et al., 2009). A study published by Danielzik et al. on 5-7 years old children determined parental overweight, low SEP, and a high birthweight as the most important risk factors for these age group, too (Danielzik et al., 2004).

There is also evidence from previous multilevel studies that factors indicating a low neighbourhood SEP were associated with overweight in young children independent of individual socioeconomic factors (Grow et al., 2010; Koller & Mielck, 2009; L. N. Oliver & Hayes, 2005; Lisa N. Oliver & Hayes, 2008). There was great heterogeneity which and how many individual SEP and neighbourhood SEP measures were considered. Most studies considered only single socioeconomic neighbourhood factors, such as measures of income, unemployment, or education, and did not combine them into an index. Some studies only took into account single proxies for describing individual SEP, such as the mother tongue (Koller & Mielck, 2009) or the insurance status (Grow et al., 2010). Moreover, these identified studies did not consider birth weight and parental overweight as potential confounders.

If not all important characteristics describing individual SEP are considered as confounders on the pathway between neighbourhood SEP and overweight, detected relations of neighbourhood SEP might reflect neighbourhood composition instead of underlying contextual relationships (Pickett & Pearl, 2001). There are also studies showing that socioeconomic measures on the area level do not necessarily reflect individual SEP (Diez-Roux et al., 2001; Pardo-Crespo et al., 2013). Pardo-Crespo et al. compared parental education and family income on the individual level and educational and family income data on the area level in the context of overweight in children, low birthweight, and smoking exposure at home. Concordance analysis showed low Cohen's kappa coefficients suggesting a poor agreement between individual and area SEP measures.

Although there is heterogeneity across published studies on how built environmental measures were assessed, studies on young children which simultaneously considered perceived or objective built environmental characteristics, neighbourhood SEP, and individual child and family factors showed comparable findings. Perceived parental neighbourhood characteristics, such as of green space, physical disorder, places to play, or access to supermarkets were not significantly associated with overweight in young children (Hawkins et al., 2009; Hrudey et al., 2015).

Hawkins et al. found out that children with no access to a private garden were significantly more likely to be overweight than children having access, adjusted for individual SEP and

further overweight risk factors (Hawkins et al., 2009). This association sustains the explanation of the significant house type variable where children living in multiple dwellings had higher odds being overweight than children living in different houses. As most residents in multiple dwellings do not have access to a private garden, children could be limited in performing outdoor physical activity in their immediate home environment. Studies focusing on outdoor play of young children found out that outdoor play was inversely associated with BMI of young children (Kimbrow et al., 2011). There is further evidence that outdoor physical activity of children happened mostly in a private yard at home (Veitch et al., 2010).

Results from studies investigating objective measures of the neighbourhood built environment and their influence on overweight in young children are also consistent with our non-significant results of age-specific playground space and park availability, even when built environmental measures based on individual home addresses were available in these studies. Based on distances to playgrounds from individual home addresses Burdette found no independent relation to overweight in 3-5 year old children while simultaneously considering aspects of neighbourhood safety, proximity to fast food restaurants, household income, age, sex, and ethnicity (Burdette, 2004). Although there were no individual home addresses available in the GME data, it was possible to consider playground space specifically designed for young children and to take into account age specific population weights of each neighbourhood.

Potwarka et al. assessed public park availability with a variety of measures. Absolute number of parks within 1 km, park areas within 1 km, and distance to the closest park from home addresses were calculated. Multivariate analysis revealed no independent association between each of this three park variables and overweight in 2-9 year old children (Potwarka et al., 2008). Potestio et al. measured spatial access to public parks and recreation areas objectively in four different ways: Total number per 10 000 residents, proportion of park area and park service area in the neighbourhood, and average distance to nearest park from postal code location of the child. The final multilevel model showed no significant association between one of the park variables and overweight in children 3-8 years old (Potestio et al., 2009).

Limitations and strengths

One of the major strengths of the two multilevel analyses is to provide new evidence for the population group of younger children because there is still a lack of knowledge how contextual neighbourhood factors influence health in early childhood, especially in Germany.

Furthermore, the study considered a wide range of indicators describing SEP both on the individual and neighbourhood level together with further important child and family factors, such as parental BMI or birthweight.

One limitation is that administrative school enrolment zones were used as a proxy for the neighbourhood environment. There is no knowledge to what extent these administrative zones correlate with the perceived and used neighbourhood environment of the children and their parents.

There were no data available on average household income on the neighbourhood level which is a further socioeconomic indicator often considered in neighbourhood studies. Moreover, no further data of potential individual risk factors, such as smoking during pregnancy, breastfeeding, or data on nutrition were available which potentially confound associations between contextual neighbourhood variables and individual overweight. However, there is evidence at least for Germany that parental overweight, high birth weight, and socioeconomic indicators are the main determinants for overweight in early childhood (Danielzik et al., 2004), and all these individual determinants were considered in multilevel modelling.

The study did not include individual data to what extent parents and children use parks or playgrounds in their living environment and which neighbourhood factors might influence parents and their children to visit public playgrounds (Miles, 2008). Besides that, playground and park space data were aggregated to the neighbourhood level because no individual home addresses were available.

For analysing random-slopes and cross-level interactions, 18 level two units might be too low. Although simulation studies showed that 18 level two units may be enough for hierarchical logistic regression modelling (Austin, 2010), our random intercept estimates should be interpreted with caution. Furthermore, due to the small number of level two units and the non-significant associations between built environmental factors and overweight multilevel mediation analysis was not possible in order to explain how much of the association between neighbourhood SEP and overweight was attributable to factors from the built environment.

As both multilevel analyses were cross-sectional conclusions about causal relationships should be made with caution. However, for all analysed factors reverse causation is very unlikely. The cross-sectional study design was not able to take into account residential mobility and to examine whether individuals were exposed to different neighbourhood environments before data collection. Besides that, selective residential mobility may bias

detected relationships between neighbourhood contexts and health. If the health outcome being analysed influence the choice of neighbourhood selection in individuals, estimates may become biased and inconsistent. Previous studies which showed biased result due to residential self-selection considered adolescents or adults (Boone-Heinonen et al., 2010; Jokela, 2014; Zick et al., 2013). There is still need for further research to what extent neighbourhood self-selection bias is present in studies analysing neighbourhood health effects in children.

6.3 Socioeconomically driven environmental neighbourhood inequalities

Two ecological studies on the neighbourhood level in Munich and Dortmund investigated whether neighbourhoods with a lower neighbourhood SEP were exposed to higher environmental burdens (noise and air pollution) and lower availability of neighbourhood public green space as a health resource. In the case study of Munich the focus was whether variations of catchment areas defining green space availability influenced relationships between neighbourhood SEP and public green space availability and the application of log-gamma regression. The case study of Dortmund considered air and noise pollution additionally and put the focus more on the development of urban health indicators being relevant for planning-related interventions and the identification of hot spot areas with available data from the city council and easy replicable methods.

In the city of Munich a low neighbourhood SEP was significantly associated with lower availability of green space. Associations were mostly consistent across models where neighbourhood green space availability was assessed with various radius-buffering methods. There was a trend that with an increasing size of the catchment area of green space availability calculated from neighbourhood centroids the strength of the negative association between neighbourhood SEP and green space decreased. Also in Dortmund neighbourhoods with a lower SEP had less public green space available and were more exposed to areas having higher NO₂ and PM₁₀ levels. Only for noise there was no significant correlation.

Previous ecological studies suggest consistent negative associations between neighbourhood income and air pollution (Crouse et al., 2009; Kingham et al., 2007; Pearce & Kingham, 2008). Moreover, Crouse et al. found a positive association between percentage of residents aged over 25 being unemployed and mean NO₂ concentrations in Montreal, Canada, which is comparable to the socioeconomic neighbourhood variable describing percentage of residents receiving either unemployment benefits or social welfare aids used in the Dortmund study.

However, there are also contradictive findings for single neighbourhood SEP indicators in urban areas. In Montreal, percentage of neighbourhood residents with no high school graduation was inversely associated with mean NO₂ (Crouse et al., 2009), and also in London neighbourhoods having higher proportions of adults with a low education had on average lower NO_x concentrations (Goodman et al., 2011).

The analysis in Dortmund revealed no significant correlation between neighbourhood deprivation and noise pollution. A study which took place in Berlin, Germany, could also find no correlation between a neighbourhood SEP index and combined noise pollution from road, trams, air traffic, and railway (Lakes et al., 2014), whereas a study from the Ruhr region found a significant negative correlation of neighbourhood income and a positive association of unemployment with road traffic noise. However, the significant Pearson correlation coefficients showed values <0.2 indicating only a low correlation (Riedel et al., 2011). There are also studies which found inverse and non-linear associations between indicators of neighbourhood SEP and measures of noise pollution. An environmental inequality analysis in Marseilles, France, found out that areas which were relatively deprived on the midlevel were most exposed to road traffic noise (Bocquier et al., 2013). A further study on road traffic noise from Paris, France, found out that neighbourhood education was positively associated with noise pollution whereas non-French citizenship was negatively associated both on the individual and neighbourhood level (Havard et al., 2011).

Environmental inequality studies on air and noise pollution showed a very heterogeneous picture on how measures of neighbourhood SEP are associated with such environmental burdens. City specific urban development, its link to specific spatial distribution of neighbourhood deprivation, and city specific housing markets could explain such mixed findings.

The results of the case study in Munich are in line with previous results showing associations between indicators of low neighbourhood SEP and decreasing neighbourhood green space availability. Studies are from cities in Germany, Britain, USA, Canada, New Zealand, and Australia which highlight the international importance of unequal distributions of neighbourhood green space in urban areas (Astell-Burt et al., 2014; Lakes et al., 2014; Mitchell et al., 2011; Mitchell & Popham, 2008; Pham et al., 2012; Richardson et al., 2010; Shanahan et al., 2014; M. Wen et al., 2013). However, there is a great heterogeneity across studies on how green space availability was defined and operationalised.

Distribution of green space by socioeconomic neighbourhood characteristics was dependent on the different definitions and types of public green which were used in previous studies. There is a noticeable trend that relations between a lower neighbourhood SEP and decreasing neighbourhood green space availability is most consistent for studies which assessed general green space, as in the Munich study, by summarizing various forms of urban green, such as parks, trees, shrubs, lawn, forests, or vegetation indices derived from remote sensing data (Astell-Burt et al., 2014; Lakes et al., 2014; Mitchell et al., 2011; Mitchell & Popham, 2008; Richardson et al., 2010; M. Wen et al., 2013). When specific types of public green were analysed, such as public parks, significant associations between a lower neighbourhood SEP and increasing green space were also found (Jones et al., 2009; Richardson et al., 2010; M. Wen et al., 2013). A study in urban New Zealand identified that disadvantaged neighbourhoods have less general green space, however, have marginally more usable green space available than more affluent neighbourhoods. Usable green space included parkland, beaches, and non-commercial forestry (Richardson et al., 2010).

Some studies applied distance based methods to measure access to green space areas which might also explain mixed findings (Jones et al., 2009; M. Wen et al., 2013). Wen et al. found out that more deprived neighbourhoods across urban areas in the USA have less availability of vegetated land, however, have shorter distances to public parks (M. Wen et al., 2013). Results from a study in the city of Bristol showed that more deprived neighbourhoods have lower mean distances to public green spaces, except of well-maintained formal green spaces with structured paths and an organised outline, and sport green spaces for which distances were higher in deprived areas (Jones et al., 2009).

Such results indicate that the distribution of different types of green space and their quality play a considerable role. In the context of health, public parks and other recreational facilities could be more relevant for physical activity (Bancroft et al., 2015; Kaczynski & Henderson, 2007) whereas overall green space or urban forests could be more important in relation to the reduction of air pollution and temperature regulation which support healthy living environments in general (Bowler et al., 2010; Nowak et al., 2006) or the positive impact on mental health outcomes (Cohen-Cline et al., 2015).

There is evidence that different geographic scales in environmental justice related studies can influence results on associations between socioeconomic indicators and environmental burdens or resources (Baden et al., 2007). For that reason, GIS based methods were applied in the Munich case study to define different catchment areas based on administrative boundaries

and centroids. Most previous studies used also administrative boundaries, predominantly census tracts, as the catchment area for the measurement of green space availability because for such areas socioeconomic factors were available (Lakes et al., 2014; Mitchell et al., 2011; Mitchell & Popham, 2008; Richardson et al., 2010; M. Wen et al., 2013). Some studies, mainly from urban planning research, applied also spatial interpolation and weighting techniques to disaggregate socioeconomic data on the area level to smaller units in order to combine them with green space measures on a smaller scale (Pham et al., 2012; Shanahan et al., 2014). Many spatial methods on the disaggregation of small area data exist (J. A. Maantay et al., 2007), and there is still need for further research to what extent spatial disaggregation methods for socioeconomic data obtain different results in environmental inequality analyses in comparison to studies relying on the original census data.

The study showed that both radius-buffering methods for defining the catchment area of neighbourhood green space, one based on administrative boundaries and one based on centroids, revealed significant negative associations between a low neighbourhood SEP and green space availability. If no individual data concerning home addresses or individual SEP are available, small administrative units provide therefore a good starting point to analyse environmental inequalities. There were differences in the strengths of the associations, especially for catchment areas based on neighbourhood centroids. With increasing radii the strength of the associations decreased. For catchment areas based on administrative neighbourhood boundaries and relating buffers, parameter estimates were more homogeneous across models. In general, results from this study suggest that both GIS methods are adequate to measure green space availability on the neighbourhood level and should be considered in future studies. This analysis showed in particular that catchment areas based on neighbourhood boundaries including a small buffer, such as of 200 m, and catchment areas based on centroids with a 1000 m radius may serve as a good proxy for analysing socioeconomic related green space inequalities on the neighbourhood level. For these measures significant and strongest associations were found, and they are comparable with other studies which used a radius of 800 m around individual home addresses considered as a common maximum walking distance for reaching neighbourhood resources or other facilities (Coombes et al., 2010; Giles-Corti et al., 2013; Gose et al., 2013; Van Dyck et al., 2009).

From a methodological point of view this study showed that GLMs offer a suitable parametric modelling strategy for positively distributed environmental variables. Therefore, it is

recommended to use this approach in future studies to investigate environmental inequalities dealing with skewed distributions of the response variable.

Limitations and strength

One of the main strengths of the case study in Munich is that various catchment areas for green space availability were considered in order to check whether these different area definitions influence the hypotheses that more deprived neighbourhoods have less green space available. Moreover, log-gamma regression from the group of generalized linear models as a powerful parametric approach was applied which adequately addressed the distribution of our response variable. The case study in Dortmund examined both environmental burdens and resources and developed indicators based on data which were routinely collected by the city administration which could make replications and comparisons across cities much easier.

Both studies focused on overall public green space availability and did not consider private green spaces. There were no detailed data on quality characteristics of single green space types available which can also vary by socioeconomic neighbourhood characteristics and influence usage of green space areas (Jones et al., 2009; L. V. Moore et al., 2008; Weiss et al., 2011). Moreover, it was not possible to calculate individual distance-based distances to green spaces or individual exposures to air and noise pollution because no home addresses were available.

A further limitation is that both studies assume spatial independency of neighbourhood observations. The presence of spatial autocorrelation violates the assumption of independent observations for regression analysis and therefore may cause biased effect estimates if not controlled for it (Goodman et al., 2011; Shanahan et al., 2014). A further uncertainty is based on the aggregated unit of analysis called the modifiable area unit problem (MAUP). Different geographic aggregations of the same data, which vary in size and shape, may cause different effect measures (J. Maantay, 2002).

7 Overall conclusions

The consideration of more than one environmental neighbourhood dimension is important for increasing knowledge on how socioeconomic, built, and social neighbourhood characteristics are associated with individual health. It offers the possibility to analyse mediating and interacting pathways. A simultaneous consideration of contextual and individual factors in multilevel modelling offers quantitative conclusions on how neighbourhood heterogeneities contribute to health inequalities and which effects of public health programmes targeting healthy living environments may be expected in relation to individual orientated interventions.

Results from multilevel analyses sustain recommendations that policies and interventions targeting overweight prevention in early childhood should address parental behaviours and the immediate home environment of the family and their children. Considering neighbourhood built environments in intervention planning additionally could result in more effective prevention strategies.

Against the background of potential health effects of public green space and air pollution, a socioeconomic unequal distribution of environmental burdens and resources may amplify health inequalities within cities. Combining socioeconomic and environmental data on the neighbourhood level, which are mostly easy accessible, allow the identification of vulnerable areas facing multiple environmental burdens which further identifies options for urban planning interventions. From a methodological point of view the combination of GIS, for defining various catchment areas of green space availability, with parametric modelling approaches for positively distributed environmental variables contributes to the evidence of unequal distributions of environmental neighbourhood resources in urban contexts.

Increasing knowledge about the health impact of the built environment and the socioeconomic distribution of environmental burdens and resources will contribute to the reconnection of urban planning and public health. A sustainable healthy city development needs transdisciplinary cooperation between urban planning and public health (Corburn, 2004; Northridge et al., 2003). Ecosocial approaches from epidemiology, concepts from environmental justice addressing socioeconomically driven environmental inequalities, and the increasing combination of epidemiological and urban planning methods, such as through GIS, contribute to this reconnection.

8 References

- Adams, J., & Wisner, B. (2002). *Environmental health in emergencies and disasters: a practical guide*. Geneva: World Health Organization.
- Agresti, A. (2013). *Categorical data analysis* (3rd ed.). Hoboken, NJ: Wiley.
- Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *19*, 716-723.
- Alin, A. (2010). Multicollinearity. *WIREs Computational Statistics*, *2*, 370-374. doi: 10.1002/wics.84
- Allison, P. D. (2005). *Imputation of categorical variables with PROC MI*. Paper presented at the SUGI 30 Proceedings, Philadelphia, Pennsylvania
- Apparicio, P., Abdelmajid, M., Riva, M., & Shearmur, R. (2008). Comparing alternative approaches to measuring the geographical accessibility of urban health services: distance types and aggregation-error issues. *Int. J. Health. Geogr.*, *7*, 7. doi: 10.1186/1476-072X-7-7
- Astell-Burt, T., Feng, X. Q., Mavoa, S., Badland, H. M., & Giles-Corti, B. (2014). Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health*, *14*. doi: 10.1186/1471-2458-14-292
- Ault, K. (2012). *Multiple imputation for ordinal variables: a comparison of SUDAAN PROC IMPUTE and SAS® PROC MI*. Paper presented at the 20th Annual SouthEast SAS Users Group (SESUG) Conference, Durham.
- Austin, P. C. (2010). Estimating multilevel logistic regression models when the number of clusters is low: a comparison of different statistical software procedures. *Int. J. Biostat.*, *6*(1). doi: 10.2202/1557-4679.1195
- Baden, B. M., Noonan, D. S., & Turaga, R. M. R. (2007). Scales of justice: Is there a geographic bias in environmental equity analysis? *J. Environ. Plann. Man.*, *50*(2), 163-185. doi: 10.1080/09640560601156433
- Bancroft, C., Joshi, S., Rundle, A., Hutson, M., Chong, C., Weiss, C. C., Genkinger, J., Neckerman, K., & Lovasi, G. (2015). Association of proximity and density of parks and objectively measured physical activity in the United States: a systematic review. *Soc. Sci. Med.*, *138*, 22-30. doi: 10.1016/j.socscimed.2015.05.034
- Barton, H., & Grant, M. (2006). A health map for the local human habitat. *J. R. Soc. Promo. Health*, *126*(6), 252-253. doi: 10.1177/1466424006070466
- Bell, B. A., Morgan, G. B., Kromrey, J. D., & Ferron, J. M. (2010). The impact of small cluster size on multilevel models: a monte carlo examination of two-level models with binary and continuous predictors. *JSM*, 4057-4067.
- Berglund, P. A. (2010). *An introduction to multiple imputation of complex sample data using SAS® v9.2*. Paper presented at the Proceedings of the SAS Global Forum 2010 (Paper 265-2010), Seattle Washington.
- Black, D. S., Townsend, P., & Davidson, N. (1980). *Inequalities in health: the Black Report*. Harmondsworth: Penguin, 1982.

- Bocquier, A., Cortaredona, S., Boutin, C., David, A., Bigot, A., Chaix, B., Gaudart, J., & Verger, P. (2013). Small-area analysis of social inequalities in residential exposure to road traffic noise in Marseilles, France. *Eur. J. Public Health*, 23(4), 540-546. doi: 10.1093/eurpub/cks059
- Bolte, G., Fromme, H., & für die GME-Studiengruppe. (2008). Umweltgerechtigkeit als Themenschwerpunkt der Gesundheits-Monitoring-Einheiten (GME) in Bayern. *UMID*, 2, 39-42.
- Bolte, G., Heissenhuber, A., von Kries, R., Liebl, B., Zapf, A., Wildner, M., Fromme, H., & für die GME-Studiengruppe. (2007). [Health monitoring units in Bavaria. Concept, aims and thematic focus of the first survey on children's environment and health]. *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz*, 50(4), 476-483. doi: 10.1007/s00103-007-0191-0
- Bolte, G., Pauli, A., & Hornberg, C. (2011). Environmental justice: social disparities in environmental exposures and health: overview. In O. N. Jerome (Ed.), *Encyclopedia of Environmental Health* (pp. 459-470). Burlington: Elsevier.
- Boone-Heinonen, J., Guilkey, D. K., Evenson, K. R., & Gordon-Larsen, P. (2010). Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood. *The international journal of behavioral nutrition and physical activity*, 7, 70. doi: 10.1186/1479-5868-7-70
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: a systematic review of the empirical evidence. *Landscape Urban. Plan.*, 97(3), 147-155. doi: 10.1016/j.landurbplan.2010.05.006
- Braubach, M., & Fairburn, J. (2010). Social inequities in environmental risks associated with housing and residential location - a review of evidence. *Eur. J. Public Health*, 20(1), 36-42. doi: 10.1093/eurpub/ckp221
- Brulle, R. J., & Pellow, D. N. (2006). Environmental justice: human health and environmental inequalities. *Annu. Rev. Public Health*, 27, 103-124. doi: 10.1146/annurev.publhealth.27.021405.102124
- Burdette, H. (2004). Neighborhood playgrounds, fast food restaurants, and crime: relationships to overweight in low-income preschool children. *Prev. Med.*, 38(1), 57-63. doi: 10.1016/j.ypmed.2003.09.029
- Chuang, Y. C., Cubbin, C., Ahn, D., & Winkleby, M. A. (2005). Effects of neighbourhood socioeconomic status and convenience store concentration on individual level smoking. *J. Epidemiol. Community Health*, 59(7), 568-573. doi: 10.1136/jech.2004.029041
- Cohen-Cline, H., Turkheimer, E., & Duncan, G. E. (2015). Access to green space, physical activity and mental health: a twin study. *J. Epidemiol. Community Health*, 69(6), 523-529. doi: 10.1136/jech-2014-204667
- Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Soc. Sci. Med.*, 70(6), 816-822. doi: 10.1016/j.socscimed.2009.11.020
- Corburn, J. (2004). Confronting the challenges in reconnecting urban planning and public health. *Am. J. Public Health*, 94(4), 541-546. doi: 10.2105/Ajph.94.4.541

- Crouse, D. L., Ross, N. A., & Goldberg, M. S. (2009). Double burden of deprivation and high concentrations of ambient air pollution at the neighbourhood scale in Montreal, Canada. *Soc. Sci. Med.*, *69*(6), 971-981. doi: 10.1016/j.socscimed.2009.07.010
- Cummins, S., Curtis, S., Diez-Roux, A. V., & Macintyre, S. (2007). Understanding and representing 'place' in health research: a relational approach. *Soc. Sci. Med.*, *65*(9), 1825-1838. doi: 10.1016/j.socscimed.2007.05.036
- Cummins, S., Stafford, M., Macintyre, S., Marmot, M., & Ellaway, A. (2005). Neighbourhood environment and its association with self rated health: evidence from Scotland and England. *J. Epidemiol. Community Health*, *59*(3), 207-213. doi: 10.1136/jech.2003.016147
- Dahlgren, G., & Whitehead, M. (1991). *Policies and strategies to promote social equity in health*. Stockholm: Institute for Future Studies.
- Danielzik, S., Czerwinski-Mast, M., Langnase, K., Dilba, B., & Muller, M. J. (2004). Parental overweight, socioeconomic status and high birth weight are the major determinants of overweight and obesity in 5-7 y-old children: baseline data of the Kiel Obesity Prevention Study (KOPS). *Int. J. Obes. Relat. Metab. Disord.*, *28*(11), 1494-1502. doi: 10.1038/sj.ijo.0802756
- De Meester, F., Van Dyck, D., De Bourdeaudhuij, I., Deforche, B., Sallis, J. F., & Cardon, G. (2012). Active living neighborhoods: is neighborhood walkability a key element for Belgian adolescents? *BMC Public Health*, *12*, 7. doi: 10.1186/1471-2458-12-7
- deFur, P. L., Evans, G. W., Hubal, E. A. C., Kyle, A. D., Morello-Frosch, R. A., & Williams, D. R. (2007). Vulnerability as a function of individual and group resources in cumulative risk assessment. *Environ. Health Perspect.*, *115*(5), 817-824. doi: 10.1289/Ehp.9332
- Diez-Roux, A. V., Kiefe, C. I., Jacobs, D. R., Jr., Haan, M., Jackson, S. A., Nieto, F. J., Paton, C. C., & Schulz, R. (2001). Area characteristics and individual-level socioeconomic position indicators in three population-based epidemiologic studies. *Ann. Epidemiol.*, *11*(6), 395-405.
- Diez Roux, A. V. (2000). Multilevel analysis in public health research. *Annu. Rev. Public Health*, *21*, 171-192. doi: 10.1146/annurev.publhealth.21.1.171
- Diez Roux, A. V. (2002). A glossary for multilevel analysis. *J. Epidemiol. Community Health*, *56*(8), 588-594. doi: 10.1136/jech.56.8.588
- Diez Roux, A. V., & Mair, C. (2010). Neighborhoods and health. *Ann. N. Y. Acad. Sci.*, *1186*, 125-145. doi: 10.1111/j.1749-6632.2009.05333.x
- Ding, D., Sallis, J. F., Kerr, J., Lee, S., & Rosenberg, D. E. (2011). Neighborhood environment and physical activity among youth a review. *Am. J. Prev. Med.*, *41*(4), 442-455. doi: 10.1016/j.amepre.2011.06.036
- Dragano, N., Hoffmann, B., Moebus, S., Moehlenkamp, S., Stang, A., Verde, P. E., Jockel, K. H., Erbel, R., Siegrist, J., & Heinz Nixdorf Recall Study, I. (2009). Traffic exposure and subclinical cardiovascular disease: is the association modified by socioeconomic characteristics of individuals and neighbourhoods? Results from a multilevel study in an urban region. *Occup. Environ. Med.*, *66*(9), 628-635. doi: 10.1136/oem.2008.044032

- Dragano, N., Hoffmann, B., Stang, A., Moebus, S., Verde, P. E., Weyers, S., Mohlenkamp, S., Schmermund, A., Mann, K., Jockel, K. H., Erbel, R., Siegrist, J., & Nixdorf Recall Study Investigat, G. (2009). Subclinical coronary atherosclerosis and neighbourhood deprivation in an urban region. *Eur. J. Epidemiol.*, *24*(1), 25-35. doi: 10.1007/s10654-008-9292-9
- Dreger, S., Meyer, N., Fromme, H., Bolte, G., & for the Study Group of the GME cohort. (2015). Environmental noise and incident mental health problems: A prospective cohort study among school children in Germany. *Environ. Res.*, *143* (Pt A), 49-54. doi: 10.1016/j.envres.2015.08.003
- Duncan, C., Jones, K., & Moon, G. (1998). Context, composition and heterogeneity: using multilevel models in health research. *Soc. Sci. Med.*, *46*(1), 97-117.
- Elkeles, T., & Mielck, A. (1993). *Soziale und gesundheitliche Ungleichheit. Theoretische Ansätze zur Erklärung von sozioökonomischen Unterschieden in Morbidität und Mortalität*. Berlin: Wissenschaftszentrum für Sozialforschung.
- Ene, M., Leighton, E. A., Blue, G. L., & Bell, B. A. (2014). *Multilevel models for categorical data using SAS® PROC GLIMMIX: the basics* Paper presented at the Southeast SAS Users Group Conference 2014.
- Feng, J., Glass, T. A., Curriero, F. C., Stewart, W. F., & Schwartz, B. S. (2010a). The built environment and obesity: a systematic review of the epidemiologic evidence. *Health Place*, *16*(2), 175-190. doi: 10.1016/j.healthplace.2009.09.008
- Feng, J., Glass, T. A., Curriero, F. C., Stewart, W. F., & Schwartz, B. S. (2010b). The built environment and obesity: a systematic review of the epidemiologic evidence. *Health Place*, *16*(2), 175-190. doi: 10.1016/j.healthplace.2009.09.008
- Flacke, J., Schüle, S. A., Köckler, H., & Bolte, G. (2016). Mapping environmental inequalities relevant for health for informing urban planning interventions - a case study in the city of Dortmund, Germany. *Int. J. Environ. Res. Public Health*, *13*(7). doi: 10.3390/ijerph13070711
- Fox, J. (2016). *Applied regression analysis and generalized linear models* (3rd ed.). Los Angeles: SAGE.
- Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. *J. Am. Plann. Assoc.*, *72*(1), 75-87. doi: 10.1080/01944360608976725
- Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. *Br. J. Sports Med.*, *44*(13), 924-933. doi: 10.1136/bjism.2009.058701
- Freedman, V. A., Grafova, I. B., & Rogowski, J. (2011). Neighborhoods and chronic disease onset in later life. *Am. J. Public Health*, *101*(1), 79-86. doi: 10.2105/ajph.2009.178640
- Freedman, V. A., Grafova, I. B., Schoeni, R. F., & Rogowski, J. (2008). Neighborhoods and disability in later life. *Soc. Sci. Med.*, *66*(11), 2253-2267. doi: 10.1016/j.socscimed.2008.01.013
- Galster, G. (2001). On the nature of neighbourhood. *Urban Studies*, *38*(12), 2111-2124. doi: 10.1080/00420980120087072

- Galvez, M. P., Pearl, M., & Yen, I. H. (2010). Childhood obesity and the built environment. *Curr. Opin. Pediatr.*, 22(2), 202-207. doi: 10.1097/MOP.0b013e328336eb6f
- Gee, G. C., & Payne-Sturges, D. C. (2004). Environmental health disparities: A framework integrating psychosocial and environmental concepts. *Environ. Health Perspect.*, 112(17), 1645-1653.
- Genereux, M., Auger, N., Goneau, M., & Daniel, M. (2008). Neighbourhood socioeconomic status, maternal education and adverse birth outcomes among mothers living near highways. *J. Epidemiol. Community Health*, 62(8), 695-700. doi: <http://dx.doi.org/10.1136/jech.2007.066167>
- Geronimus, A. T., & Bound, J. (1998). Use of census-based aggregate variables to proxy for socioeconomic group: evidence from national samples. *Am. J. Epidemiol.*, 148(5), 475-486.
- Giles-Corti, B., Bull, F., Knuiaman, M., McCormack, G., Van Niel, K., Timperio, A., Christian, H., Foster, S., Divitini, M., Middleton, N., & Boruff, B. (2013). The influence of urban design on neighbourhood walking following residential relocation: Longitudinal results from the RESIDE study. *Soc. Sci. Med.*, 77, 20-30. doi: 10.1016/j.socscimed.2012.10.016
- Goodman, A., Wilkinson, P., Stafford, M., & Tonne, C. (2011). Characterising socio-economic inequalities in exposure to air pollution: a comparison of socio-economic markers and scales of measurement. *Health Place*, 17(3), 767-774. doi: 10.1016/j.healthplace.2011.02.002
- Gose, M., Plachta-Danielzik, S., Willie, B., Johannsen, M., Landsberg, B., & Muller, M. J. (2013). Longitudinal influences of neighbourhood built and social environment on children's weight status. *Int. J. Environ. Res. Public Health*, 10(10), 5083-5096. doi: 10.3390/ijerph10105083
- Grafova, I. B., Freedman, V. A., Kumar, R., & Rogowski, J. (2008). Neighborhoods and obesity in later life. *Am. J. Public Health*, 98(11), 2065-2071. doi: 10.2105/ajph.2007.127712
- Grow, H. M., Cook, A. J., Arterburn, D. E., Saelens, B. E., Drewnowski, A., & Lozano, P. (2010). Child obesity associated with social disadvantage of children's neighborhoods. *Soc. Sci. Med.*, 71(3), 584-591. doi: 10.1016/j.socscimed.2010.04.018
- Gürlich, K., Herr, C., Hendrowarsito, L., Weber, A., Nennstiel-Ratzel, U., Wildner, M., Liebl, B., Bolte, G., Jorres, R. A., Kolb, S., & GME-Studiengruppe, f. d. (2016). [Respiratory and allergic diseases of children: temporal trends, urban-rural differences, and in association with environmental tobacco smoke exposure]. *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz*, 59(12), 1566-1576. doi: 10.1007/s00103-016-2458-9
- Hammarstrom, A., Johansson, K., Annandale, E., Ahlgren, C., Alex, L., Christianson, M., Elwer, S., Eriksson, C., Fjellman-Wiklund, A., Gilenstam, K., Gustafsson, P. E., Harryson, L., Lehti, A., Stenberg, G., & Verdonk, P. (2014). Central gender theoretical concepts in health research: the state of the art. *J. Epidemiol. Community Health*, 68(2), 185-190. doi: 10.1136/jech-2013-202572
- Harrell, F. E. (2001). *Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis*. New York: Springer.
- Havard, S., Reich, B. J., Bean, K., & Chaix, B. (2011). Social inequalities in residential exposure to road traffic noise: an environmental justice analysis based on the RECORD Cohort Study. *Occup. Environ. Med.*, 68(5), 366-374. doi: 10.1136/oem.2010.060640

- Hawkins, S. S., Pearce, A., Cole, T. J., Law, C., Millennium Cohort Study Child Health, G., Dezaux, C., Peckham, C., Bedford, H., Rahi, J., Griffiths, L. J., Cumberland, P., & Bartington, S. (2009). Perceived and objective measures of the neighbourhood environment and overweight in preschool children and their mothers. *Int. J. Pediatr. Obes.*, 4(3), 183-192. doi: 10.1080/17477160802596155
- Hosmer, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied logistic regression* (3rd ed.). Hoboken: Wiley.
- Hrudey, E. J., Kunst, A. E., Stronks, K., & Vrijkotte, T. G. (2015). Do neighborhood characteristics in Amsterdam influence adiposity at preschool age? *Int. J. Environ. Res. Public Health*, 12(5), 5561-5580. doi: 10.3390/ijerph120505561
- Inagami, S., Cohen, D. A., Brown, A. F., & Asch, S. M. (2009). Body mass index, neighborhood fast food and restaurant concentration, and car ownership. *J. Urban Health*, 86(5), 683-695. doi: 10.1007/s11524-009-9379-y
- Jennings, V., Gaither, C. J., & Schulterbrandt Gragg, R. (2012). Promoting environmental justice through urban green space access: a synopsis. *Environ. Justice*, 5(1), 1-7. doi: 10.1089/env.2011.0007
- Jokela, M. (2014). Are neighborhood health associations causal? A 10-year prospective cohort study with repeated measurements. *Am. J. Epidemiol.*, 180(8), 776-784. doi: 10.1093/aje/kwu233
- Jones, A., Hillsdon, M., & Coombes, E. (2009). Greenspace access, use, and physical activity: understanding the effects of area deprivation. *Prev. Med.*, 49(6), 500-505. doi: 10.1016/j.ypmed.2009.10.012
- Kaczynski, A. T., & Henderson, K. A. (2007). Environmental correlates of physical activity: a review of evidence about parks and recreation. *Leisure Sci.*, 29(4), 315-354. doi: 10.1080/01490400701394865
- Kawachi, I., Subramanian, S. V., & Almeida-Filho, N. (2002). A glossary for health inequalities. *J. Epidemiol. Community Health*, 56(9), 647-652.
- Kimbro, R. T., Brooks-Gunn, J., & McLanahan, S. (2011). Young children in urban areas: links among neighborhood characteristics, weight status, outdoor play, and television watching. *Soc. Sci. Med.*, 72(5), 668-676. doi: 10.1016/j.socscimed.2010.12.015
- Kingham, S., Pearce, J., & Zawar-Reza, P. (2007). Driven to injustice? Environmental justice and vehicle pollution in Christchurch, New Zealand. *Transportation Research Part D: Transport and Environment*, 12(4), 254-263. doi: 10.1016/j.trd.2007.02.004
- Kleiser, C., Schaffrath Rosario, A., Mensink, G. B., Prinz-Langenohl, R., & Kurth, B. M. (2009). Potential determinants of obesity among children and adolescents in Germany: results from the cross-sectional KiGGS Study. *BMC Public Health*, 9, 46. doi: 10.1186/1471-2458-9-46
- Koller, D., & Mielck, A. (2009). Regional and social differences concerning overweight, participation in health check-ups and vaccination. Analysis of data from a whole birth cohort of 6-year old children in a prosperous German city. *BMC Public Health*, 9, 43. doi: 10.1186/1471-2458-9-43
- Krieger, N. (1994). Epidemiology and the web of causation: has anyone seen the spider? *Soc. Sci. Med.*, 39(7), 887-903.

- Krieger, N. (2001a). A glossary for social epidemiology. *J. Epidemiol. Community Health*, 55(10), 693-700. doi: 10.1136/jech.55.10.693
- Krieger, N. (2001b). Theories for social epidemiology in the 21st century: an ecosocial perspective. *Int. J. Epidemiol.*, 30(4), 668-677.
- Krieger, N. (2003). Genders, sexes, and health: what are the connections - and why does it matter? *Int. J. Epidemiol.*, 32(4), 652-657. doi: 10.1093/ije/dyg156
- Krieger, N. (2011). *Epidemiology and the people's health: theory and context*. New York: Oxford University Press.
- Krieger, N., Williams, D. R., & Moss, N. E. (1997). Measuring social class in US public health research: concepts, methodologies, and guidelines. *Annu. Rev. Public Health*, 18, 341-378. doi: 10.1146/annurev.publhealth.18.1.341
- Kruize, H., Droomers, M., van Kamp, I., & Ruijsbroek, A. (2014). What causes environmental inequalities and related health effects? An analysis of evolving concepts. *Int. J. Environ. Res. Public Health*, 11(6), 5807-5827. doi: 10.3390/ijerph110605807
- Krull, J. L., & MacKinnon, D. P. (2001). Multilevel modeling of individual and group level mediated effects. *Multivariate Behavioral Research*, 36(2), 249-277.
- Lakes, T., Bruckner, M., & Kramer, A. (2014). Development of an environmental justice index to determine socio-economic disparities of noise pollution and green space in residential areas in Berlin. *J. Environ. Plann. Man.*, 57(4), 538-556. doi: 10.1080/09640568.2012.755461
- Lalloue, B., Monnez, J. M., Padilla, C., Kihal, W., Le Meur, N., Zmirou-Navier, D., & Deguen, S. (2013). A statistical procedure to create a neighborhood socioeconomic index for health inequalities analysis. *Int J Equity Health*, 12. doi: 10.1186/1475-9276-12-21
- Larsen, K., & Merlo, J. (2005). Appropriate assessment of neighborhood effects on individual health: integrating random and fixed effects in multilevel logistic regression. *Am. J. Epidemiol.*, 161(1), 81-88. doi: 10.1093/aje/kwi017
- Leventhal, T., & Brooks-Gunn, J. (2000). The neighborhoods they live in: the effects of neighborhood residence on child and adolescent outcomes. *Psychol. Bull.*, 126(2), 309-337. doi: 10.1037/0033-2909.126.2.309
- Levy, J. I. (2008). Is epidemiology the key to cumulative risk assessment? *Risk Anal.*, 28(6), 1507-1513. doi: 10.1111/j.1539-6924.2008.01121.x
- Maantay, J. (2002). Mapping environmental injustices: pitfalls and potential of geographic information systems in assessing environmental health and equity. *Environ. Health Perspect.*, 110, 161-171.
- Maantay, J. A., Maroko, A. R., & Herrmann, C. (2007). Mapping population distribution in the urban environment: the cadastral-based expert dasymetric system (CEDS). *Cartography and Geographic Information Science*, 34(2), 77-102. doi: 10.1559/152304007781002190
- Maas, C. J. M., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology*, 1(3), 86-92.

- Macintyre, S., & Ellaway, A. (2003). Neighborhoods and health: an overview. In I. Kawachi (Ed.), *Neighborhoods and health* (pp. 352). Oxford; New York: Oxford University Press.
- Macintyre, S., Ellaway, A., & Cummins, S. (2002). Place effects on health: how can we conceptualise, operationalise and measure them? *Soc. Sci. Med.*, *55*(1), 125-139. doi: 10.1016/S0277-9536(01)00214-3
- MacKinnon, D. P., Fairchild, A. J., & Fritz, M. S. (2007). Mediation analysis. *Annu. Rev. Psychol.*, *58*, 593-614. doi: 10.1146/annurev.psych.58.110405.085542
- Mair, C., Diez Roux, A. V., & Galea, S. (2008). Are neighbourhood characteristics associated with depressive symptoms? A review of evidence. *J. Epidemiol. Community Health*, *62*(11), 940-946. doi: 10.1136/jech.2007.066605
- Marmot, M. (2005). Social determinants of health inequalities. *Lancet*, *365*(9464), 1099-1104. doi: 10.1016/S0140-6736(05)71146-6
- Matthews, S. A., & Yang, T.-C. (2010). Exploring the role of the built and social neighborhood environment in moderating stress and health. *Ann. Behav. Med.*, *39*(2), 170-183. doi: <http://dx.doi.org/10.1007/s12160-010-9175-7>
- McLaren, L., & Hawe, P. (2005). Ecological perspectives in health research. *J. Epidemiol. Community Health*, *59*(1), 6-14. doi: 10.1136/jech.2003.018044
- Meijer, M., Rohl, J., Bloomfield, K., & Grittner, U. (2012). Do neighborhoods affect individual mortality? A systematic review and meta-analysis of multilevel studies. *Soc. Sci. Med.*, *74*(8), 1204-1212. doi: 10.1016/j.socscimed.2011.11.034
- Menard, S. W. (2002). *Applied logistic regression analysis* (2nd ed.). Thousand Oaks, Calif.: Sage Publications.
- Merlo, J., Chaix, B., Ohlsson, H., Beckman, A., Johnell, K., Hjerpe, P., Rastam, L., & Larsen, K. (2006). A brief conceptual tutorial of multilevel analysis in social epidemiology: using measures of clustering in multilevel logistic regression to investigate contextual phenomena. *J. Epidemiol. Community Health*, *60*(4), 290-297. doi: 10.1136/jech.2004.029454
- Merlo, J., Chaix, B., Yang, M., Lynch, J., & Rastam, L. (2005). A brief conceptual tutorial on multilevel analysis in social epidemiology: interpreting neighbourhood differences and the effect of neighbourhood characteristics on individual health. *J. Epidemiol. Community Health*, *59*(12), 1022-1028. doi: 10.1136/jech.2004.028035
- Merlo, J., Yang, M., Chaix, B., Lynch, J., & Rastam, L. (2005). A brief conceptual tutorial on multilevel analysis in social epidemiology: investigating contextual phenomena in different groups of people. *J. Epidemiol. Community Health*, *59*(9), 729-736. doi: 10.1136/jech.2004.023929
- Messer, L. C., Laraia, B. A., Kaufman, J. S., Eyster, J., Holzman, C., Culhane, J., Elo, I., Burke, J. G., & O'Campo, P. (2006). The development of a standardized neighborhood deprivation index. *J. Urban Health*, *83*(6), 1041-1062. doi: 10.1007/s11524-006-9094-x
- Metcalfe, A., Lail, P., Ghali, W. A., & Sauve, R. S. (2011). The association between neighbourhoods and adverse birth outcomes: a systematic review and meta-analysis of multi-level studies. *Paediatr. Perinat. Epidemiol.*, *25*(3), 236-245. doi: 10.1111/j.1365-3016.2011.01192.x

- Mielck, A. (2000). *Soziale Ungleichheit und Gesundheit: empirische Ergebnisse, Erklärungsansätze, Interventionsmöglichkeiten* (1st ed.). Bern [u.a.]: Huber.
- Mielck, A. (2005). *Soziale Ungleichheit und Gesundheit: Einführung in die aktuelle Diskussion* (1st ed.). Bern: Huber.
- Miles, R. (2008). Neighborhood disorder, perceived safety, and readiness to encourage use of local playgrounds. *Am. J. Prev. Med.*, 34(4), 275-281. doi: 10.1016/j.amepre.2008.01.007
- Mistler, S. A. (2013a). A SAS® macro for applying multiple imputation to multilevel data. *Proceedings of the SAS Global Forum 2013, San Francisco, California: Contributed Paper (Statistics and Data Analysis)*.
- Mistler, S. A. (2013b). A SAS® macro for computing pooled likelihood ratio tests with multiply imputed data. *Proceedings of the SAS Global Forum 2013, San Francisco, California: Contributed Paper (Statistics and Data Analysis)*
- Mitchell, R., Astell-Burt, T., & Richardson, E. A. (2011). A comparison of green space indicators for epidemiological research. *J. Epidemiol. Community Health*, 65(10), 853-858. doi: 10.1136/jech.2010.119172
- Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet*, 372(9650), 1655-1660. doi: 10.1016/S0140-6736(08)61689-X
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*, 339, b2535. doi: 10.1136/bmj.b2535
- Moinuddin, R., Matheson, F. I., & Glazier, R. H. (2007). A simulation study of sample size for multilevel logistic regression models. *BMC Med. Res. Methodol.*, 7. doi: 10.1186/1471-2288-7-34
- Moore, K., Diez Roux, A. V., Auchincloss, A., Evenson, K. R., Kaufman, J., Mujahid, M., & Williams, K. (2013). Home and work neighbourhood environments in relation to body mass index: the Multi-Ethnic Study of Atherosclerosis (MESA). *J. Epidemiol. Community Health*, 67(10), 846-853. doi: 10.1136/jech-2013-202682
- Moore, L. V., Diez Roux, A. V., Evenson, K. R., McGinn, A. P., & Brines, S. J. (2008). Availability of recreational resources in minority and low socioeconomic status areas. *Am. J. Prev. Med.*, 34(1), 16-22. doi: 10.1016/j.amepre.2007.09.021
- Morello-Frosch, R., & Shenassa, E. D. (2006). The environmental "Riskscape" and social inequality: implications for explaining maternal and child health disparities. *Environ. Health Perspect.*, 114(8), 1150-1153. doi: 10.1289/Ehp.8930
- Northridge, M. E., Sclar, E. D., & Biswas, P. (2003). Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities. *J. Urban Health*, 80(4), 556-568. doi: 10.1093/jurban/jtg064
- Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Gree.*, 4(3-4), 115-123. doi: 10.1016/j.ufug.2006.01.007

- Oliver, L. N., & Hayes, M. V. (2005). Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. *Can. J. Public Health.*, 96(6), 415-420.
- Oliver, L. N., & Hayes, M. V. (2008). Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health*, 8, 16. doi: 10.1186/1471-2458-8-16
- Orban, E., McDonald, K., Sutcliffe, R., Hoffmann, B., Fuks, K. B., Dragano, N., Viehmann, A., Erbel, R., Jockel, K. H., Pundt, N., & Moebus, S. (2016). Residential road traffic noise and high depressive symptoms after five years of follow-up: results from the Heinz Nixdorf Recall Study. *Environ. Health Perspect.*, 124(5), 578-585. doi: 10.1289/ehp.1409400
- Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L. D., Bauman, A. E., Hugo, G., Saelens, B. E., & Sallis, J. F. (2007). Neighborhood walkability and the walking behavior of Australian adults. *Am. J. Prev. Med.*, 33(5), 387-395. doi: 10.1016/j.amepre.2007.07.025
- Pampalon, R., Hamel, D., Gamache, P., Philibert, M. D., Raymond, G., & Simpson, A. (2012). An area-based material and social deprivation index for public health in Quebec and Canada. *Can. J. Public Health.*, 103(8 Suppl 2), S17-22.
- Pampalon, R., Hamel, D., Gamache, P., & Raymond, G. (2009). A deprivation index for health planning in Canada. *Chronic Dis. Can.*, 29(4), 178-191.
- Pardo-Crespo, M. R., Narla, N. P., Williams, A. R., Beebe, T. J., Sloan, J., Yawn, B. P., Wheeler, P. H., & Juhn, Y. J. (2013). Comparison of individual-level versus area-level socioeconomic measures in assessing health outcomes of children in Olmsted County, Minnesota. *J. Epidemiol. Community Health*, 67(4), 305-310. doi: 10.1136/jech-2012-201742
- Pearce, J., & Kingham, S. (2008). Environmental inequalities in New Zealand: a national study of air pollution and environmental justice. *Geoforum*, 39(2), 980-993. doi: 10.1016/j.geoforum.2007.10.007
- Pellow, D. N. (2000). Environmental inequality formation - toward a theory of environmental injustice. *Am. Behav. Sci.*, 43(4), 581-601. doi: 10.1177/0002764200043004004
- Pham, T. T. H., Apparicio, P., Seguin, A. M., Landry, S., & Gagnon, M. (2012). Spatial distribution of vegetation in Montreal: an uneven distribution or environmental inequity? *Landscape Urban. Plan.*, 107(3), 214-224. doi: 10.1016/j.landurbplan.2012.06.002
- Pickett, K. E., & Pearl, M. (2001). Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *J. Epidemiol. Community Health*, 55(2), 111-122.
- Pollack, C. E., Cubbin, C., Ahn, D., & Winkleby, M. (2005). Neighbourhood deprivation and alcohol consumption: does the availability of alcohol play a role? *Int. J. Epidemiol.*, 34(4), 772-780. doi: 10.1093/ije/dyi026
- Ponce, N. A., Hoggatt, K. J., Wilhelm, M., & Ritz, B. (2005). Preterm birth: the interaction of traffic-related air pollution with economic hardship in Los Angeles neighborhoods. *Am. J. Epidemiol.*, 162(2), 140-148. doi: 10.1093/aje/kwi173

- Portier, C. J., Thigpen, T. K., Carter, S. R., Dilworth, C. H., Grambsch, A. E., Gohlke, J., Hess, J., Howard, S. N., Luber, G., Lutz, J. T., Maslak, T., Prudent, N., Radtke, M., Rosenthal, J. P., Rowles, T., Sandifer, P. A., Scheraga, J., Schramm, P. J., Strickman, D., Trtanj, J. M., & Whung, P.-Y. (2010). *A human health perspective on climate change: a report outlining the research needs on the human health effects of climate change*. Retrieved 17/8/2016, from www.niehs.nih.gov/climate/report doi:10.1289/ehp.100227
- Potestio, M. L., Patel, A. B., Powell, C. D., McNeil, D. A., Jacobson, R. D., & McLaren, L. (2009). Is there an association between spatial access to parks/green space and childhood overweight/obesity in Calgary, Canada? *The international journal of behavioral nutrition and physical activity*, 6, 77. doi: 10.1186/1479-5868-6-77
- Potwarka, L. R., Kaczynski, A. T., & Flack, A. L. (2008). Places to play: association of park space and facilities with healthy weight status among children. *J. Community Health*, 33(5), 344-350. doi: 10.1007/s10900-008-9104-x
- Prince, S. A., Kristjansson, E. A., Russell, K., Billette, J.-M., Sawada, M. C., Ali, A., Tremblay, M. S., & Prud'homme, D. (2012). Relationships between neighborhoods, physical activity, and obesity: a multilevel analysis of a large Canadian city. *Obesity*, 20(10), 2093-2100. doi: <http://dx.doi.org/10.1038/oby.2011.392>
- Prince, S. A., Kristjansson, E. A., Russell, K., Billette, J. M., Sawada, M., Ali, A., Tremblay, M. S., & Prud'homme, D. (2011). A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada. *Int. J. Environ. Res. Public Health*, 8(10), 3953-3978. doi: 10.3390/ijerph8103953
- Reading, R., Jones, A., Haynes, R., Daras, K., & Emond, A. (2008). Individual factors explain neighbourhood variations in accidents to children under 5 years of age. *Soc. Sci. Med.*, 67(6), 915-927. doi: 10.1016/j.socscimed.2008.05.018
- Renalds, A., Smith, T. H., & Hale, P. J. (2010). A systematic review of built Environment and health. *Fam. Community Health*, 33(1), 68-78.
- Richardson, E., Pearce, J., Mitchell, R., Day, P., & Kingham, S. (2010). The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility. *BMC Public Health*, 10. doi: 10.1186/1471-2458-10-240
- Richter, M., & Hurrelmann, K. (2006). Gesundheitliche Ungleichheit: Ausgangsfragen und Herausforderungen. In M. Richter & K. Hurrelmann (Eds.), *Gesundheitliche Ungleichheit. Grundlagen, Probleme, Perspektiven* (pp. 11-31). Wiesbaden: Verlag für Sozialwissenschaften.
- Riedel, N., Hoffmann, B., Fuks, K., Jöckel, K.-H., & Dragano, N. (2011). Health inequalities in the city: assessing the concurrence of social and environmental risks in the Ruhr Area. *UMID*, 2, 85-90.
- Riva, M., Gauvin, L., Apparicio, P., & Brodeur, J. M. (2009). Disentangling the relative influence of built and socioeconomic environments on walking: the contribution of areas homogenous along exposures of interest. *Soc. Sci. Med.*, 69(9), 1296-1305. doi: 10.1016/j.socscimed.2009.07.019
- Riva, M., Gauvin, L., & Barnett, T. A. (2007). Toward the next generation of research into small area effects on health: a synthesis of multilevel investigations published since July 1998. *J. Epidemiol. Community Health*, 61(10), 853-861. doi: 10.1136/jech.2006.050740

- Romaus, R., & Weizel, R. (2004). *Münchner Armutsbericht - Fortschreibung 2002*: Landeshauptstadt München Sozialreferat.
- Ross, N. A., Tremblay, S., Khan, S., Crouse, D., Tremblay, M., & Berthelot, J. M. (2007). Body mass index in urban Canada: neighborhood and metropolitan area effects. *Am. J. Public Health, 97*(3), 500-508. doi: 10.2105/AJPH.2004.060954
- Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., Chapman, J. E., & Kerr, J. (2009). Neighborhood built environment and income: examining multiple health outcomes. *Soc. Sci. Med., 68*(7), 1285-1293. doi: 10.1016/j.socscimed.2009.01.017
- Sampson, R. J., Morenoff, J. D., & Earls, F. (1999). Beyond social capital: spatial dynamics of collective efficacy for children. *Am. Sociol. Rev., 64*(5), 633-660. doi: 10.2307/2657367
- Sampson, R. J., Morenoff, J. D., & Gannon-Rowley, T. (2002). Assessing "neighborhood effects": social processes and new directions in research. *Annu Rev Sociol, 28*, 443-478. doi: 10.1146/annurev.soc.28.110601.141114
- SAS Institute. (2013a). The FACTOR procedure *SAS/STAT® 13.1 User's Guide*: SAS Institute, Cary, North Carolina, USA.
- SAS Institute. (2013b). The GENMOD procedure *SAS/STAT® 13.1 User's Guide*: SAS Institute, Cary, North Carolina, USA.
- SAS Institute. (2013c). The GLIMMIX procedure *SAS/STAT® 13.1 User's Guide*: SAS Institute, Cary, North Carolina, USA.
- SAS Institute. (2013d). The MI procedure *SAS/STAT® 13.1 User's Guide*: SAS Institute, Cary, North Carolina, USA.
- SAS Institute. (2013e). The MIANALYZE procedure *SAS/STAT® 13.1 User's Guide*: SAS Institute, Cary, North Carolina, USA.
- Schabenberger, O. (2007). *Growing up fast: SAS 9.2 enhancements to the GLIMMIX procedure*. Paper presented at the Proceedings of the SAS Global Forum 2007 (Paper 177-2007).
- Schreier, H. M., & Chen, E. (2013). Socioeconomic status and the health of youth: a multilevel, multidomain approach to conceptualizing pathways. *Psychol. Bull., 139*(3), 606-654. doi: 10.1037/a0029416
- Schüle, S. A., & Bolte, G. (2015). Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: a systematic review of multilevel studies. *PLoS One, 10*(4), e0123456. doi: 10.1371/journal.pone.0123456
- Schüle, S. A., Fromme, H., & Bolte, G. (2016). Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. *Environ. Res., 150*, 328-336. doi: 10.1016/j.envres.2016.06.024
- Schüle, S. A., Gabriel, K. M., & Bolte, G. (2017). Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: an environmental inequality analysis in a large German city applying generalized linear models. *Int. J. Hyg. Environ. Health, 220*(4), 711-718. doi: 10.1016/j.ijheh.2017.02.006

- Schüle, S. A., von Kries, R., Fromme, H., & Bolte, G. (2016). Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: a multilevel study in a large German city. *BMC obesity*, 3, 25. doi: 10.1186/s40608-016-0106-4
- Schulz, A., & Northridge, M. E. (2004). Social determinants of health: implications for environmental health promotion. *Health Educ. Behav.*, 31(4), 455-471. doi: 10.1177/1090198104265598
- Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics*, 6, 461-464.
- Scott, M. M., Dubowitz, T., & Cohen, D. A. (2009). Regional differences in walking frequency and BMI: what role does the built environment play for Blacks and Whites? *Health Place*, 15(3), 882-887. doi: 10.1016/j.healthplace.2009.02.010
- Sellström, E., & Bremberg, S. (2006). The significance of neighbourhood context to child and adolescent health and well-being: a systematic review of multilevel studies. *Scand. J. Public Health*, 34(5), 544-554. doi: 10.1080/14034940600551251
- Shanahan, D. F., Lin, B. B., Gaston, K. J., Bush, R., & Fuller, R. A. (2014). Socio-economic inequalities in access to nature on public and private lands: a case study from Brisbane, Australia. *Landscape Urban. Plan.*, 130, 14-23. doi: 10.1016/j.landurbplan.2014.06.005
- Shrewsbury, V., & Wardle, J. (2008). Socioeconomic status and adiposity in childhood: a systematic review of cross-sectional studies 1990-2005. *Obesity*, 16(2), 275-284. doi: 10.1038/oby.2007.35
- Siegrist, J., & Marmot, M. G. (2006). *Social inequalities in health: new evidence and policy implications*. Oxford ; New York: Oxford University Press.
- Slater, S. J., Ewing, R., Powell, L. M., Chaloupka, F. J., Johnston, L. D., & O'Malley, P. M. (2010). The association between community physical activity settings and youth physical activity, obesity, and body mass index. *J. Adolesc. Health*, 47(5), 496-503. doi: <http://dx.doi.org/10.1016/j.jadohealth.2010.03.017>
- Soobader, M. J., LeClere, F. B., Hadden, W., & Maury, B. (2001). Using aggregate geographic data to proxy individual socioeconomic status: does size matter? *Am. J. Public Health*, 91(4), 632-636. doi: Doi 10.2105/Ajph.91.4.632
- Spearman, C. (2010). The proof and measurement of association between two things. *Int. J. Epidemiol.*, 39(5), 1137-1150. doi: 10.1093/Ije/Dyq191
- Springer, K. W., Mager Stellman, J., & Jordan-Young, R. M. (2012). Beyond a catalogue of differences: a theoretical frame and good practice guidelines for researching sex/gender in human health. *Soc. Sci. Med.*, 74(11), 1817-1824. doi: 10.1016/j.socscimed.2011.05.033
- Stafford, M., Cummins, S., Macintyre, S., Ellaway, A., & Marmot, M. (2005). Gender differences in the associations between health and neighbourhood environment. *Soc. Sci. Med.*, 60(8), 1681-1692. doi: 10.1016/j.socscimed.2004.08.028
- Steinkamp, G. (1999). Soziale Ungleichheit in Mortalität und Morbidität. In W. Schlicht & H. H. Dickhuth (Eds.), *Gesundheit für alle. Fiktion oder Realität?* (pp. 101-154). Stuttgart, New York: Hofmann, Schattauer.

- Subramanian, S. V., Jones, K., & Duncan, C. (2003). Multilevel methods for public health research. In I. Kawachi (Ed.), *Neighborhoods and health* (pp. 352). Oxford ; New York: Oxford University Press.
- Sundquist, K., Eriksson, U., Kawakami, N., Skog, L., Ohlsson, H., & Arvidsson, D. (2011). Neighborhood walkability, physical activity, and walking behavior: the Swedish Neighborhood and Physical Activity (SNAP) study. *Soc. Sci. Med.*, 72(8), 1266-1273. doi: <http://dx.doi.org/10.1016/j.socscimed.2011.03.004>
- Szasz, A., & Meuser, M. (1997). Environmental inequalities: literature review and proposals for new directions in research and theory. *Current Sociology*, 45(3), 99-120. doi: 10.1177/001139297045003006
- Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Boston: Pearson Education.
- Tamburlini, G. (2002). Children's special vulnerability to environmental health hazards: an overview. In G. Tamburlini, O. S. von Ehrenstein & R. Bertollini (Eds.), *Children's health and environment: a review of evidence. A joint report from the European Environment Agency and the WHO Regional Office for Europe. Environmental Issue Report No. 29* (pp. 18–28). Copenhagen: European Environment Agency. Retrieved 17/8/2016, from <http://www.euro.who.int/document/e75518.pdf>.
- Van Buuren, S. (2011). Multiple imputation of multilevel data. In J. J. Hox & J. K. Roberts (Eds.), *Handbook of Advanced Multilevel Analysis*. New York: Routledge.
- Van Dyck, D., Cardon, G., Deforche, B., Owen, N., Sallis, J. F., & De Bourdeaudhuij, I. (2010). Neighborhood walkability and sedentary time in Belgian adults. *Am. J. Prev. Med.*, 39(1), 25-32. doi: 10.1016/j.amepre.2010.03.004
- Van Dyck, D., Cardon, G., Deforche, B., Sallis, J. F., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. *Prev. Med.*, 50 Suppl 1, S74-S79. doi: 10.1016/j.ypmed.2009.07.027
- Van Dyck, D., Deforche, B., Cardon, G., & De Bourdeaudhuij, I. (2009). Neighbourhood walkability and its particular importance for adults with a preference for passive transport. *Health Place*, 15(2), 496-504. doi: 10.1016/j.healthplace.2008.08.010
- Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health*, 12, 807. doi: 10.1186/1471-2458-12-807
- Veitch, J., Salmon, J., & Ball, K. (2010). Individual, social and physical environmental correlates of children's active free-play: a cross-sectional study. *The international journal of behavioral nutrition and physical activity*, 7, 11. doi: 10.1186/1479-5868-7-11
- Voigtländer, S., Vogt, V., Mielck, A., & Razum, O. (2014). Explanatory models concerning the effects of small-area characteristics on individual health. *International journal of public health*, 59(3), 427-438. doi: 10.1007/s00038-014-0556-8
- Walker, G. (2012). *Environmental justice: concepts, evidence and politics*. London: Routledge.

- Wang, J., Xie, H., & Fischer, J. H. (2012). *Multilevel models: applications using SAS*. Berlin; Boston: De Gruyter; Higher Education Press.
- Wang, M. C., Kim, S., Gonzalez, A. A., MacLeod, K. E., & Winkleby, M. A. (2007). Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. *J. Epidemiol. Community Health*, *61*(6), 491-498. doi: 10.1136/jech.2006.051680
- Weber, A., Herr, C., Hendrowarsito, L., Meyer, N., Nennstiel-Ratzel, U., von Mutius, E., Bolte, G., Colon, D., Kolb, S., & for the GME Study Group. (2016). No further increase in the parent reported prevalence of allergies in Bavarian preschool children: results from three cross-sectional studies. *Int. J. Hyg. Environ. Health*, *219*(4-5), 343-348. doi: 10.1016/j.ijheh.2016.02.001
- Weiss, C. C., Purciel, M., Bader, M., Quinn, J. W., Lovasi, G., Neckerman, K. M., & Rundle, A. G. (2011). Reconsidering access: park facilities and neighborhood disamenities in New York City. *J. Urban Health*, *88*(2), 297-310. doi: 10.1007/s11524-011-9551-z
- Wen, M., & Kowaleski-Jones, L. (2012). The built environment and risk of obesity in the United States: racial-ethnic disparities. *Health Place*, *18*(6), 1314-1322. doi: 10.1016/j.healthplace.2012.09.002
- Wen, M., & Zhang, X. (2009). Contextual effects of built and social environments of urban neighborhoods on exercise: a multilevel study in Chicago. *Am. J. Health Promot.*, *23*(4), 247-254. doi: <http://dx.doi.org/10.4278/ajhp.07052448>
- Wen, M., Zhang, X. Y., Harris, C. D., Holt, J. B., & Croft, J. B. (2013). Spatial disparities in the distribution of parks and green spaces in the USA. *Ann. Behav. Med.*, *45*, S18-S27. doi: 10.1007/s12160-012-9426-x
- Whitehead, M. (1987). *The health divide: inequalities in health in the 1980's*. London: Health Education Council.
- WHO. (2010). *A conceptual framework for action on the social determinants of health (social determinants of health discussion paper 2)*. Retrieved 17/8/2016, from http://www.who.int/sdhconference/resources/ConceptualframeworkforactiononSDH_eng.pdf
- WHO. (2016a). Health Impact Assessment (HIA) - Glossary of terms used. Retrieved 17/8/2016, from <http://www.who.int/hia/about/glos/en/index1.html>
- WHO. (2016b). Social determinants of health. Retrieved 17/8/2016, from http://www.who.int/social_determinants/en/
- WHO. (2016c). Social determinants of health - Key concepts. Retrieved 17/8/2016, from http://www.who.int/social_determinants/thecommission/finalreport/key_concepts/en/
- Williams, B. L., Pennock-Roman, M., Suen, H. K., Magsumbol, M. S., & Ozdenerol, E. (2007). Assessing the impact of the local environment on birth outcomes: a case for HLM. *J. Expo. Sci. Environ. Epidemiol.*, *17*(5), 445-457. doi: 10.1038/sj.jes.7500537
- Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape Urban. Plan.*, *125*, 234-244. doi: 10.1016/j.landurbplan.2014.01.017

- Yang, T. C., & Matthews, S. A. (2010). The role of social and built environments in predicting self-rated stress: a multilevel analysis in Philadelphia. *Health Place, 16*(5), 803-810. doi: 10.1016/j.healthplace.2010.04.005
- Zeka, A., Melly, S. J., & Schwartz, J. (2008). The effects of socioeconomic status and indices of physical environment on reduced birth weight and preterm births in Eastern Massachusetts. *Environ. Health, 7*(34). doi: 10.1186/1476-069x-7-60
- Zick, C. D., Hanson, H., Fan, J. X., Smith, K. R., Kowaleski-Jones, L., Brown, B. B., & Yamada, I. (2013). Re-visiting the relationship between neighbourhood environment and BMI: an instrumental variables approach to correcting for residential selection bias. *Int. J. Behav. Nutr. Phys. Act., 10*. doi: 10.1186/1479-5868-10-27

9 Acknowledgements

First and foremost, I would like to express my gratitude to Prof. Dr. Gabriele Bolte for supervising my dissertation. Her continual guidance and support helped me through all times of my research. Besides my supervisor, I would like to thank Prof. Dr. Hajo Zeeb, Prof. Dr. Susanne Moebus, Prof. Dr. Ulrike Haug, and Prof. Dr. Karin Wolf-Ostermann for their interest in my work.

Moreover, I am very grateful to my group of colleagues and former colleagues from the Department of Social Epidemiology within the Institute of Public Health and Nursing Research. My special thanks goes to my office mate Stefanie Dreger for sharing and discussing all kind of academic, organizational, and private issues coming along with doing a PhD. I wish to thank Birgit Reineke for her support in all kind of upcoming data management issues. Without her support my quantitative research part would have undoubtedly been more difficult. Many thanks also to Katharina Gabriel for sharing her academic perspective from Geography, to Tanja Brüchert and Josephine Göldner for their assistance in conducting my systematic review, and to Christina Müller for supporting me with her English proficiency.

For data provision and supporting me in developing my study design, my further thanks goes to the GME study group, the department of statistic in the city of Munich (Ronald Bauch), the building directorate in the city of Munich (Gabriele Maliska), the department of city planning and building regulations in the city of Munich (Dr. Andreas Peter, Kurt Damaschke), and Prof. Dr. Werner Brannath (Competence Centre for Clinical Trials, University of Bremen).

I would like to acknowledge all members of the junior research group Salus (“The City as a healthy living environment independent of social inequalities”) with a special gratitude to Prof. Dr. Heike Köckler for the excellent guidance of the group and the generation of transdisciplinary dialogues between our five PhD students. I greatly benefited from the discussions and meetings with the other PhDs Rehana Shresta, Raphael Sieber, Lisa Waegerle, and Ursula Hemetek. My further thanks goes to Prof. Dr. Johannes Flacke for widening my horizon concerning the application of Geographic Information Systems.

Finally, my sincere thanks goes to Johanna, my friends, parents, and grandparents motivating me through all times of my PhD period!

Annex A Publications for cumulative dissertation

Annex A.1 Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: a systematic review of multilevel studies

Reference:

Schüle, S. A., & Bolte, G. (2015). Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: a systematic review of multilevel studies. *PloS One*, *10*(4), e0123456. doi: 10.1371/journal.pone.0123456

Link to full article:

<http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0123456>

Due to a production fault concerning the illustration of tables by the Journal Plos One, a submitted manuscript is attached containing all corrections. A corrigendum of the article is in progress and will be published under the same reference mentioned above.

Interactive and Independent Associations between the Socioeconomic and Objective Built Environment on the Neighbourhood Level and Individual Health: A Systematic Review of Multilevel Studies

Steffen Andreas Schüle*, Gabriele Bolte

Department of Social Epidemiology, Institute of Public Health and Nursing Research,
University of Bremen, Bremen, Germany

* Corresponding author, E-mail: steffen.schuele@uni-bremen.de

Abstract

Background: The research question how contextual factors of neighbourhood environments influence individual health has gained increasing attention in public health research. Both socioeconomic neighbourhood characteristics and factors of the built environment play an important role for health and health-related behaviours. However, their reciprocal relationships have not been systematically reviewed so far. This systematic review aims to identify studies applying a multilevel modelling approach which consider both neighbourhood socioeconomic position (SEP) and factors of the objective built environment simultaneously in order to disentangle their independent and interactive effects on individual health.

Methods: The three databases PubMed, PsycINFO, and Web of Science were systematically searched with terms for title and abstract screening. Grey literature was not included. Observational studies from USA, Canada, Australia, New Zealand, and Western European countries were considered which analysed simultaneously factors of neighbourhood SEP and the objective built environment with a multilevel modelling approach. Adjustment for individual SEP was a further inclusion criterion.

Results: Thirty-three studies were included in qualitative synthesis. Twenty-two studies showed an independent association between characteristics of neighbourhood SEP or the built environment and individual health outcomes or health-related behaviours. Twenty-one studies found cross-level or within-level interactions either between neighbourhood SEP and the built environment, or between neighbourhood SEP or the built environment and individual characteristics, such as sex, individual SEP or ethnicity. Due to the large variation of study design and heterogeneous reporting of results the identification of consistent findings was problematic and made quantitative analysis not possible.

Conclusions: There is a need for studies considering multiple neighbourhood dimensions and applying multilevel modelling in order to clarify their causal relationship towards individual health. Especially, more studies using comparable characteristics of neighbourhood SEP and the objective built environment and analysing interactive effects are necessary to disentangle health impacts and identify vulnerable neighbourhoods and population groups.

Background

Since the late 1990s an increasing number of epidemiological studies have analysed whether the socioeconomic, built, social or ethnic neighbourhood environment have an independent effect on individual health outcomes or health-related behaviours [1,2]. There is an overall conclusion that underlying mechanisms of the association between neighbourhood environments and health are quite complex and both mediating and interacting mechanisms should be considered. Therefore, various conceptual models were developed describing pathways explaining associations between neighbourhood context and individual health [2-9].

For a better systematization of possible connections between neighbourhood characteristics and individual health a distinction between compositional and contextual effects is widely established in the literature. A compositional effect is present if health differences between neighbourhoods are attributed to individual characteristics, the so-called composition of neighbourhood residents, such as individual health behaviours, health status or individual socioeconomic position (SEP). The term contextual effect is used if variables at the neighbourhood level, such as features of the built or social environment, have an effect on individual health outcomes while adjusting for possible confounders at the individual level to avoid an ecological fallacy [10-12]. This more abstract distinction has also been discussed critically in the literature [13]. However, it provides a good basis for suggesting conceptual pathways in which ways neighbourhood context can affect individual health.

To separate out potential contextual neighbourhood effects from individual effects a multilevel modelling approach is an appropriate analytic strategy addressing such issues. Multilevel modelling offers the possibility to sort out how much variance of health outcomes between neighbourhoods is related to individual factors and how much is explained by contextual factors on the neighbourhood level. A multilevel model combines data on at least two hierarchical levels: aggregated variables on the neighbourhood level (2nd level) and variables on the individual level from residents within the neighbourhood (1st level). Thus, simultaneous examinations of independent effects of each level and interactions within and across levels on individual health outcomes are possible while accounting for the potential dependency of individual observations sharing the same characteristics of higher level variables [11,14].

Systematic reviews showed that most neighbourhood studies focused on factors of neighbourhood SEP from aggregated census data. They analysed whether neighbourhood SEP

has a contextual effect on individual health while simultaneously adjusting for individual socio-demographic characteristics. Many of these studies found out that a low neighbourhood SEP was independently associated with poor health, such as increased mortality risk, poor self-rated health, depressive symptoms, low birth weight or cardiovascular risk factors [15-22]. Evidence from these studies raised the question which underlying factors explain independent associations between neighbourhood SEP and individual health. Many studies hypothesized that poor neighbourhoods are exposed to a poor built environment, such as air pollution, lack of green space or an unhealthy food environment. Thus, an integrated consideration of neighbourhood SEP, built environmental factors and socioeconomic factors on the individual level is needed to explore underlying mechanisms how neighbourhood SEP and the built environment are connected and associated with health.

The term ‘built environment’ can be systematically differentiated from the term ‘natural environment’. Both terms belong to the physical environment. Schulz and Northridge define the built environment as that part of the physical environment which *“encompass all of the buildings, spaces, and products that are created or significantly modified by people (...)”* (Page 456) [23]. In urban environments none of the environment is natural because even parks including natural components, such as green space or water, are to some extent created or modified by people, and can be assigned to the built environment, too. Thus, the built environment covers many dimensions in an urban context, such as land use, transportation systems, services, public resources, zoning regulations or building characteristics [24]. The built environment can be measured subjectively or objectively. Subjective measures are mostly self-reported perceptions conducted in survey questionnaires. Objective measures can be either collected in the field or obtained from existing land use data in Geographic Information Systems (GIS). Systematic reviews focusing on the evidence how factors of the built environment influence health indicated the increasing importance of this neighbourhood dimension [25-29]. These reviews considered primarily cardiovascular risk factors, such as overweight or low physical activity. Though studies of the built environment gave partly inconsistent results, all reviews concluded that the built environment can significantly impact individual health.

The links between neighbourhood SEP and exposures from the built environment and health are captured by the environmental justice framework. A conceptual model derived from this framework contains two main hypothetical pathways how socioeconomic position, environmental exposures and health are connected: The first hypothesis states that

environmental exposures are social unequally distributed (exposure variation by SEP), the second hypothesis states that neighbourhoods or individuals with a low SEP are more vulnerable to environmental exposures [30].

Both neighbourhood SEP and built environmental factors play a significant role for explaining health inequalities between neighbourhoods. However, to the best of our knowledge a systematic review focusing on to what extent both characteristics of neighbourhood SEP and the built environment are simultaneously considered in epidemiological neighbourhood studies, and how they interact with each other or with individual characteristics has not been carried out so far.

The overall goal of this systematic review is to identify epidemiological studies with a multilevel modelling approach considering characteristics of neighbourhood SEP and the objective built environment simultaneously in order to disentangle their independent or interactive effects on individual health outcomes.

The primary research questions is, how characteristics of neighbourhood SEP and the objective built environment are associated with individual health outcomes or health-related behaviours if both dimensions are considered simultaneously in multilevel modelling. Secondary, the review summarizes knowledge on interactions between neighbourhood SEP, the built environment and individual SEP.

Methods

The three databases PubMed, PsycINFO, and Web of Science were searched on the 5th of November 2013. The research question, search strategy and inclusion criteria were developed before the review process. There is no registered protocol reference number, however. Search terms were generated for title and abstract screening in order to identify neighbourhood studies with a multilevel modelling approach considering both socioeconomic and built environmental factors. In order to identify synonyms for the terms ‘neighbourhood’, ‘built environment’, ‘socioeconomic environment’ and ‘multilevel modelling’, the terminology in already existing reviews and their cited studies dealing with these topics were additionally considered. In PubMed terms of Medical Subject Headings were taken into account (Table 1). Title and abstracts were screened by two reviewers independently with predefined inclusion criteria. A third reviewer was consulted if there was disagreement. If one of the inclusion criteria could not be clearly identified in the abstract, the full text of the record was analysed for eligibility by one reviewer. An explicit search on grey literature was not performed

because the review focused on observational epidemiological studies applying advanced statistical modelling which are most likely to be found in scientific journals. However, to take into account potential publication bias, we did not limit our analysis on papers published in peer-reviewed journals. References of finally included records were additionally checked. Neighbourhood studies applying a multilevel modelling approach are a relatively recent study type. Therefore, we did not restrict our search to a specific time period.

As suggested by Krieger et al. the term ‘socioeconomic position’ (SEP) is used. The term ‘SEP’ combines actual economic and social resources with prestige-based characteristics which relatively position individuals, households and neighbourhoods in society [31,32].

The following inclusion criteria were applied:

1. Observational studies applying multilevel modelling and considering factors of the neighbourhood environment as higher level variables. Studies focusing exclusively on other environments were excluded, such as the school or work environment. Moreover, studies taking into account subjects from clinical settings or focusing on study populations with health problems were also excluded. Clinical trials and intervention studies were excluded, too.
2. Studies from USA, Canada, Australia, New Zealand and Western European Countries
3. Physical or mental health outcomes, or health-related behaviours measured at the individual level.
4. Simultaneous consideration of at least one characteristic of neighbourhood SEP from the whole neighbourhood population and at least one objective measure of the built environment in one multilevel model. Studies were excluded if neighbourhood SEP was only considered as an adjustment variable.
5. Measures of the objective built environment. Papers were excluded which considered only measures of the perceived built environment. Studies showed that there is low to moderate agreement between objective and perceived measures of the built environment [33,34]. Moreover, studies which assessed the neighbourhood built environment via observational methods with trained staff were also excluded due to limitations in validity [35].
6. Adjustment for at least one individual socioeconomic factor. Ethnicity alone was not considered as a sufficient indicator for socioeconomic position [36]. Therefore, studies considering only specific ethnic population samples were also excluded.

Each included study was described in a summary table and coded related to: outcome, population sample, country, considered factors of neighbourhood SEP and the objective built environment, and individual and further contextual factors. Because the review focused on neighbourhood SEP and the objective built environment, other considered neighbourhood characteristics in the study, such as measures of crime, social capital, residential stability, perceived built environment or segregation were indicated also in the last column (Table 2).

In a qualitative analysis independent and interactive effects of the built environment and neighbourhood SEP towards individual health outcomes were visualized in four tables grouped by similar health outcomes or health-related behaviours. All variables with a p-value <0.05 in the final multilevel model were reported as statistically significant. No quantitative assessment for risk of bias in individual studies was performed. However, in each study sample size, number of observations per neighbourhood and total number of considered neighbourhood clusters were checked, because simulation studies showed that small sample sizes in multilevel studies result in biased effect estimates [37-40]. The review was conducted in accordance to the PRISMA statement [41]. A checklist is provided in the supplements.

Results

After removing of duplicates 858 records were taken into account for abstract screening. 686 records were excluded based on abstracts and titles. There was a disagreement on 14 abstracts resulting in an agreement of 91.4% between the two independent reviewers. 172 records were included into full text analysis, and 24 of them met all inclusion criteria. Nine studies were additionally identified through the analysis of references from the 24 papers selected by full text analysis. These nine studies also underwent abstract screening and full text analysis. Finally, 33 studies were considered for qualitative analysis (Figure 1).

Description of studies and sample size assessment

Except of one study, all had a cross-sectional study design and most of them were conducted in the United States (Table 2). Seven studies investigated exclusively outcomes measuring various forms of physical activity [42-48]. One of these seven studies analysed people 45 years or older [44] and one used data from adolescents aged 13-15 years [46]. The other five analysed an adult population sample.

Six studies examined exclusively measures indicating overweight or obesity either directly with the Body Mass Index (BMI) as a continuous variable or with BMI thresholds for overweight or obesity [49-54]. Two of them used data from older adults [49,50].

Five studies analysed both measures of physical activity and overweight [55-59] including one study which considered additionally mental and physical quality of life, and depressive symptoms [59]. One of these studies used data from students aged 13-16 years [58].

Four studies investigated how neighbourhood context was associated with perinatal health outcomes [60-63] and one longitudinal study focused on child accidents and injuries in children aged 0-5 years [64]. Five studies analysed self-rated health or self-reported health problems [65-69], and two of them considered a population sample 55 years or older [67,68]. One study focused exclusively on stress [70], one on smoking [71], one on heavy alcohol consumption [72] and two on objectively measured coronary artery calcification in adults aged 45-75 years [73,74].

Regarding characteristics of neighbourhood SEP 16 studies calculated an index capturing various socioeconomic characteristics of the neighbourhood population [47,49-52,54-57,65-72]. The others used single indicators of neighbourhood SEP, such as measures of income, education, poverty or unemployment.

The objective built environment was described with a variety of measures. Indices for walkability, land use mix and urbanity were calculated. Single land use types were also considered, such as retail, recreational areas, restaurants, fast food outlets, cultural and education institutions, or health and human services. Environmental pollution, such as from traffic or waste sites, was mainly investigated in studies focusing on perinatal health, mental health or self-rated health. Eleven studies calculated built environmental measures on the individual level [49,51,57,60-63,71-74], such as individual distances from residential addresses to shops or main roads.

There was a great heterogeneity concerning sample size both of individual observations and neighbourhood clusters. Sample size ranged from 637 to 425,752 individual observations and the number of considered neighbourhood clusters ranged from 24 up to 4,604 neighbourhoods. Unfortunately, only a minority of included studies gave detailed descriptive information about the number of observations per neighbourhood. Referring to simulation studies performed on sample sizes for multilevel models, most of the reviewed studies showed a sufficient size of neighbourhoods and individual observations [37-40]. However,

due to missing information in many studies about the range of individual observations within neighbourhood clusters we could not assess whether these effect estimates could be biased.

Associations between socioeconomic and built environments and physical activity

Two studies detected associations between neighbourhood SEP and physical activity independent from the built environment and individual factors (Table 3). In the first study a high neighbourhood income was negatively associated with walking for transport and positively with motorized transport [43], and in the second a high neighbourhood education was positively associated with various measures of walking [44]. One study found an interaction between neighbourhood SEP and sex [47]: The positive association between a high neighbourhood SEP and physical activity was mitigated for men.

Seven studies detected associations between the built environment and physical activity measures independent from neighbourhood SEP and individual factors. Three found a positive association between a walkability index and walking behaviours and physical activity [43,45,59]. Moreover, a walkability index was inversely associated with motorized transport [43]. One study detected an unexpected positive association between a walkability index and self-reported sitting behaviour and objectively measured sedentary time [42]. Urbanity was positively associated with utilitarian walking and negatively with recreational walking [44]. One study detected an independent positive association between number of restaurants and bars and regular exercise [47]. A further study analysing physical activity in students found a negative association between a calculated compactness index and sport participation and a positive association between number of sport facilities and sport participation [58].

Most studies considering single land use types, such as retail or recreational areas, found no associations. In five studies interactions were detected. Studies showed that associations between recreational land use, retail or availability of restaurants varied by sex or ethnicity [55-57]. One study showed a positive association between park areas and leisure time physical activity only for women [55]. An inverse association between green space and overall physical activity was observed only for men [56]. The same study showed a positive association between number of restaurants and overall physical activity only for women and a positive association between number of convenience stores and overall physical activity only for men. A third study demonstrated a positive association between number of markets and utilitarian walking only for non-Hispanic whites, a negative association between street connectivity and recreational walking only for African Americans, and a negative association

between block length and recreational walking was slightly stronger for non-Hispanic whites [57].

One study detected two interactions: One between a walkability index and individual reported reasons why people choose their neighbourhood and another between the walkability index and education. There was a positive association between a walkability index and walking for transport only for people who choose their neighbourhood because of a good perceived neighbourhood environment (closeness to job, school, shops, services or good perceived walkability) and only for people with 12 or more years of education [48]. In a second study neighbourhood income moderated the association between walkability and physical activity. A positive association between walkability and two outcomes of average activity level and moderate-to-vigorous physical activity was only significant in low income neighbourhoods [46].

Associations between socioeconomic and built environments and overweight

Eight of eleven studies showed significant associations between indicators of neighbourhood SEP and BMI, overweight or obesity independent from individual and built environmental factors (Table 4). Three studies found a negative association between a high neighbourhood SEP and BMI, overweight or obesity [49,50,52]. Two found a positive association between a low neighbourhood SEP and BMI [51,54]. A high neighbourhood income was negatively associated with BMI and obesity [58], a low neighbourhood income was positively associated with BMI and obesity [59], and a low neighbourhood education was positively associated with BMI [53].

Two studies on overweight showed interactions between neighbourhood SEP and individual characteristics. One study found out that an unexpected inverse association between a low neighbourhood SEP and overweight or obesity was only significant for men [56]. A further study detected a negative association between a high neighbourhood SEP and BMI only for non-Hispanic whites [57].

Seven studies detected significant associations between built environmental factors and measures of overweight independent from neighbourhood SEP and individual characteristics. Two studies detected an independent inverse association between measures of street connectivity and BMI or obesity [52,58] and one of them showed a positive association between distances to parks and obesity [52]. Low walkability was positively associated with overweight or obesity in one study [59]. There was a negative association between density of

sport facilities in a one mile radius around home address and BMI [49]. A further study found an unexpected negative association between number of restaurants and overweight or obesity [56]. A further study showed a positive association between number of restaurants and BMI, however, the total number of restaurants included also fast food outlets [54].

In six studies interactions were shown. A negative association between street connectivity, number of parks in a one mile radius around the home address and BMI was only significant for non-Hispanic whites [57] and an inverse association between air pollution and obesity was only significant for women [50]. One study showed a significant positive association between number of convenience stores, fast food restaurants, park areas and overweight or obesity only for women [55]. A further study detected that a positive association between fast food outlets and BMI was mitigated for car owners [54].

There was a negative association between proximity to ethnic markets and supermarkets from home address and BMI only for women and, on the other hand, a positive association between neighbourhood density of grocery stores and BMI also only for women [51]. A further study detected a significant positive association between number of specialty stores and overweight or obesity only for women, too. The same study found an inverse association between green space and overweight or obesity for women and a positive association for men, however. Moreover, a significant positive association between summer outdoor facilities and the two outcomes of overweight and obesity was also only detected for women [56].

Associations between socioeconomic and built environments and health outcomes and health-related behaviours

Most studies detected significant associations between neighbourhood SEP and health outcomes or health-related behaviours (Table 5). Six studies found significant associations between neighbourhood SEP and individual health outcomes or health-related behaviours independent from the built environment and individual characteristics. A high neighbourhood income was positively associated with physical quality of life [59]. One study found a positive association between a high neighbourhood SEP and heavy alcohol consumption [72]. A further study detected a positive association between neighbourhood unemployment and artery calcification [74]. There was an inverse association between a low neighbourhood SEP and a health score derived from self-reported health problems. Higher values of the score indicated better health [66]. Neighbourhood unemployment was positively associated with bad self-rated health [65]. One study which analysed disability in people aged 55 or older

detected a negative association between a high neighbourhood SEP and minor reported body limitations [68].

Three studies detected associations between built environmental factors and health outcomes independent from neighbourhood SEP and individual factors. A walkability index was inversely associated with mental quality of life and positively with more depressive symptoms [59]. One study found a negative association between traffic and a health score calculated from self-reported health problems. Higher values of the score indicated better health [66]. In another study waste sites and traffic were positively associated with reported day-to-day stress [70].

In eight studies factors of neighbourhood SEP or the built environment interacted with individual characteristics. There was a positive association between a low neighbourhood SEP and reported heart problems only for women aged 55 years or older [67]. One study detected that an inverse association between a high neighbourhood SEP and number of smoked cigarettes per day was stronger for residents with a higher individual SEP [71]. Neighbourhood unemployment interacted both with sex and traffic in a further study. For men there was a positive association between neighbourhood unemployment and artery calcification with an individual distance to the next major road <100 meter from their home address. Unexpectedly, a positive association between neighbourhood unemployment and artery calcification was significant for women with a distance to the next major road >100 meter [73]. Another study found a positive association between neighbourhood unemployment and bad self-rated health only for women [69]. One study considered neighbourhood SEP as a moderator on the association between individual reported stress and a calculated health score from self-reported health problems. Higher values of the score indicated better health. The negative association between higher reported stress and a higher health score was mitigated in areas with a high neighbourhood SEP and stronger in areas with present residual waste operations [66]. In a further study, a positive association between a low neighbourhood SEP and self-reported limitations in daily activities from people aged 55 or older was only significant for men [68].

In the only identified study on smoking, the positive association between convenience store density per square mile and number of smoked cigarettes per day was mitigated for individuals with a higher SEP and, in contrast, was stronger in neighbourhoods with a high SEP. A positive association between number of convenience stores in a one mile radius around home address and number of smoked cigarettes was also stronger in neighbourhoods

with a high SEP. Furthermore, a negative association between distance to convenience stores from home address and number of smoked cigarettes per day was stronger in neighbourhoods with a high SEP [71].

One study found a positive association between distance to a major road ≤ 50 m from home address and artery calcification only for men [74]. One study on self-rated health showed a positive significant association between a lower food score and bad self-rated health only for men. Lower values of three other scores (bank/building society score, physical environment score, health service score) were significantly positively associated with bad self-rated health only for women [69]. A further study exploring the same built environmental variables found out that a low physical environment score was positively associated with bad self-rated health and was stronger for non-working study participants [65].

Associations between socioeconomic and built environments and perinatal outcomes and child health

Most studies on perinatal health found interactive associations (Table 6). Only one study showed that a high neighbourhood income was independently positively associated with birth weight and negatively with small for gestational age [61]. A further study on child accidents and injuries did not find an association either of neighbourhood unemployment nor the built environment [64].

One study gave an interaction between neighbourhood SEP and maternal risk factors. The overall inverse association between neighbourhood poverty and lower birth weight was stronger for individuals with rare maternal risk factors [60].

Regarding the built environment mostly traffic-related measures were analysed. Only one study found an independent negative association between air pollutants and birth weight [60]. All other built environmental factors interacted with neighbourhood SEP or individual factors or were not significant. One study detected a positive association between distance to highways from home address, percentage of open space and birth weight only for mothers with a high education [61]. In one study a positive association between proximity to highways and three outcomes of preterm birth, low birth weight, and small for gestational age was only significant in neighbourhoods with a high neighbourhood income. Moreover, the positive association between proximity to highways from home address and the two outcomes of preterm birth and low birth weight were only significant for mothers with a university education [62]. However, in a further study a positive association between distance weighted

traffic density and preterm birth was only significant in neighbourhoods with a low SEP index in winter time [63].

Discussion

This systematic review identified and qualitatively analysed studies applying multilevel modelling which simultaneously considered characteristics of neighbourhood SEP and the objective built environment and analysed their effects on individual health outcomes or health-related behaviours.

Sixteen studies found associations between neighbourhood SEP and individual health independent from built environmental and individual characteristics. Fourteen studies showed associations between built environmental characteristics and individual health independent from neighbourhood SEP and individual characteristics. In seven studies simultaneous independent associations of neighbourhood SEP and the objective built environment were identified. Twenty-one studies showed cross-level or within-level interactions either between neighbourhood SEP and the built environment, or between neighbourhood SEP and individual characteristics, or between the built environment and individual characteristics.

Although we grouped our studies by similar health outcomes, a systematic assessment to what extent neighbourhood SEP and the built environment influenced individual health and health-related behaviour independently and dependently from each other or were modified by individual characteristics was difficult. The most frequently analysed outcomes were measures of physical activity and overweight. A lower neighbourhood SEP was mostly associated with higher BMI, overweight, obesity, bad self-rated health or artery calcification independent from built environmental and individual factors [51,53,54,59,65,66,74]. However, most studies analysing measures of physical activity did not find associations between neighbourhood SEP and measures of physical activity. Objective built environmental metrics indicating higher walkability were often associated with measures of higher individual physical activity independent from neighbourhood SEP and individual factors [43,45,59].

This review showed that interactions play an important role. Individual characteristics, such as sex, ethnicity or individual SEP, often modified associations between neighbourhood SEP or the objective built environment and individual health. However, it became not clear how neighbourhood SEP and built environmental characteristics interacted with sex. There were characteristics of the built environment and neighbourhood SEP from which only women's or men's health benefited or suffered [50,51,55,56,67-69,73,74]. No systematic findings which

specific factors of neighbourhood SEP or the built environment are more harmful to men's or women's health could be detected.

Various moderating associations of neighbourhood SEP on associations between the built environment and health were identified. Some studies observed an impact of a health promoting built environment only in neighbourhoods with a low SEP [46]. On the other hand there were studies demonstrating that associations between factors of a higher built environmental burden and poor health or negative health behaviours were only significant or stronger in neighbourhoods with a high SEP [62,71]. In contrast, one study found out that only individuals living in a low SEP neighbourhoods were affected by higher built environmental burdens [63].

A variety of measures both of socioeconomic and built environments were studied which may partly explain mixed results. Especially concerning metrics and definitions of built environmental variables, there was a great heterogeneity. The majority of all studies calculated weighted numbers of various facilities, such as stores, sport and recreational facilities, parks, or restaurants. There was a great variety concerning the weights that were used. The most used weights were: fixed number of residents, number of neighbourhood residents, neighbourhood size or square kilometre, distance based buffer around each individual's home address, or the centroid of the neighbourhood. Moreover, many studies calculated indices, mostly derived from factor analysis. The number and kind of built environmental variables contained in these scores was too heterogeneous for drawing comparisons. The only comparable index across studies was the walkability index. A minority of studies calculated distance based measures, such as to main roads, stores or parks. Distances were calculated either from individual home addresses or from neighbourhood centroids. The limited comparability across studies is consistent with previous systematic reviews, which focused either on a specific health outcome or exclusively on one neighbourhood environmental dimension [18,21,26,28].

A further explanation for inconsistent results could be that built environments and socioeconomic neighbourhood structures vary across countries and continents. Besides that, these variations can be shaped by country specific social and housing policies on the neighbourhood level.

Studies were included which considered at least one individual socioeconomic factor, one factor of neighbourhood SEP and one of the objective built environment. However, apart from

sex and age, studies varied by the number of included individual and contextual variables that might explain mixed results, too. Individual data on health behaviours, such as smoking or nutrition, and family status (e.g. marital status) were in some studies additionally considered. Many studies included also factors of the social environment, such as crime or characteristics of social capital in the neighbourhood. Individual and contextual characteristics may mediate associations on the pathway between neighbourhood SEP and individual health or between built environmental factors and individual health. The study by Reading et al. is an example where individual factors completely mediated the association between neighbourhood context and child accidents [64].

Limitations

A first limitation is that our qualitative analysis only visualized significance or non-significance and direction of associations or interactions and did not make any comparisons on strength of the associations. The operationalization of variables was too heterogeneous across studies to perform meaningful quantitative comparisons. A second limitation is that our search code was mainly based on title and abstract screening. Besides that the Medical Subject Headings used in the PubMed database may not correspond to selected keywords by authors. Therefore, our search strategy was maybe not sensitive enough and could not identify all relevant studies. To reduce this limitation, we checked all references of included studies. We assumed that there were no relevant studies in grey literature. Therefore, we did not perform a separate search in sources of grey literature. Our assumption was sustained by the fact that we could not identify relevant grey literature which was cited in included studies.

Strengths

The main strength of this review is that we exclusively focused on studies which considered both characteristics of neighbourhood SEP and the objective built environment simultaneously in multilevel models with the additional consideration of individual factors. We were able to analyse how these two neighbourhood dimensions were interrelated and interacted with individual variables. This systematic interaction analysis on both the neighbourhood and the individual level revealed new insight which role these dimensions play in epidemiological neighbourhood research and identified where further research is needed. A further strength is that the systematic search was not restricted to specific health outcomes or age and population groups. As a result, we could identify for which health

outcomes, health-related behaviours or population groups evidence is lacking or results are most inconsistent.

Recommendations for future research

Based on our results we suggest the following recommendations for future research: Firstly, the consideration of more than one environmental neighbourhood dimension is important for generating more evidence on how socioeconomic, built and social neighbourhood characteristics are associated with individual health. It offers the possibility to analyse mediating and interacting pathways. There is still a lack of knowledge to what extent the built environment mediates effects of neighbourhood SEP on individual health. Being aware of potential reciprocal relationships between neighbourhood SEP and the built environment provides a better basis analysing interactions with individual characteristics, such as sex, individual SEP or health behaviours. Increasing knowledge about the health impact of the built environment will contribute to the reconnection of urban planning and public health. There is an upcoming call in public health sciences that for a sustainable healthy city development there is a need for updating and refreshing the connection between urban planning and public health [24,75]. Moreover, conceptual models from the scientific field of risk assessment with a specific focus on different forms of vulnerability and cumulative environmental exposures on the individual and neighbourhood level may provide a good basis for identifying synergies between vulnerability analysis in epidemiology and cumulative risk assessment [76,77].

Secondly, there is a need to adhere to guidelines on how results from multilevel modelling should be reported. One key feature of multilevel models is that they are able to sort out variance components both on the neighbourhood and individual level which provide important information how individual health varies between and within neighbourhoods and how much of these variance can be explained by contextual factors. However, to give a systematic overview about variance components and to draw conclusions on how much of the built and socioeconomic environment contributes to health disparities was impossible in this review, because some studies reported measures on variance components and some not. Already existing glossaries and tutorials about multilevel modelling, which support a better reporting of multilevel results should receive more attention [12,78,79].

Thirdly, in some studies it was not clear what kind of cross-level or within-level interactions was analysed. Therefore, we encourage researchers to systematically report if and which

cross-level and within-level interactions were analysed regardless of their statistical significance. Moreover, most studies did not provide descriptive statistics about sample sizes of individual observations per neighbourhood cluster which is important for assessing potential bias of effect or variance estimates. Publishing such statistical information would make quantitative comparisons of multilevel models across studies easier.

Fourthly, our review revealed a great heterogeneity of metrics and definitions of variables describing the built environment. The only and most consistent index across studies was the walkability index. More of such standardized indices measuring the built environment would increase comparability across studies. The application of GIS which are increasingly used in public health research can facilitate this development especially when distance based measures are developed.

Fifthly, all of our identified studies, except of one, were cross-sectional and therefore results should be interpreted with caution. There is a need of conducting studies with a longitudinal design to prevent the problem of reverse causation.

Finally, more studies considering both environmental dimensions are needed which focus on children, because they are more vulnerable to environmental burdens than other population groups [80]. Moreover, there is a lack of studies analysing how neighbourhood SEP and built environmental factors influence mental health outcomes, such as depression, or health-related risk behaviours, such as smoking or alcohol consumption.

Conclusions

This systematic review showed that a simultaneous consideration of neighbourhood SEP, built environmental characteristics and individual factors is important for analysing pathways how neighbourhood context influence individual health outcomes and health-related behaviours. There is a need for comparable studies considering multiple neighbourhood dimensions and analysing interactive and mediating processes both between contextual factors and individual characteristic and between contextual factors itself because our review identified mixed results. For an integrated analysis of both aggregated neighbourhood SEP and built environmental factors a multilevel modelling approach is appropriate because it allows to consider individual factors concurrently. This study design can generate more evidence to what extent the built environment mediates associations between neighbourhood SEP and health, and how individual characteristics, such as sex or individual SEP, act as effect modifiers in order to identify vulnerable neighbourhoods and population groups.

Acknowledgments

We would like to express our gratitude to Tanja Brüchert and Josephine göldner for assistance in title and abstract screening. Furthermore, we would like to thank the members of the Junior Research Group Salus (Jufo-Salus), especially Heike Köckler, Rehana Shrestha, Lisa Waegerle, Ursula Hemetek and Raphael Sieber, for their valuable comments on the first draft of this review.

Jufo-Salus (Junior Research Group “The City as a healthy living environment independent of social inequalities”): TU Dortmund University, Faculty of Spatial Planning, Department of Urban and Regional Planning, Dortmund, Germany (Sabine Baumgart, Heike Köckler, Andrea Rüdiger, Raphael Sieber, Lisa Waegerle); University of Bremen, Faculty of Human and Health Sciences, Institute of Public Health and Nursing Research, Department of Social Epidemiology, Bremen, Germany (Gabriele Bolte, Ursula Hemetek, Steffen Schüle); University of Applied Sciences Fulda, Faculty of Caring and Health, Public Health Institute, Department of Health Promotion, Fulda, Germany (Beate Blättner, Ursula Hemetek); University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC), Department of Urban and Regional Planning and Geo-Information Management, Enschede, Netherlands (Johannes Flacke, Rehana Shrestha)

Literature

1. Diez Roux AV (2001) Investigating neighborhood and area effects on health. *Am J Public Health* 91: 1783-1789.
2. Diez Roux AV, Mair C (2010) Neighborhoods and health. *Biology of Disadvantage: Socioeconomic Status and Health* 1186: 125-145.
3. Schreier HM, Chen E (2013) Socioeconomic status and the health of youth: a multilevel, multidomain approach to conceptualizing pathways. *Psychological bulletin* 139: 606-654.
4. Chaix B (2009) Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research agenda. *Annu Rev Public Health* 30: 81-105.
5. Daniel M, Moore S, Kestens Y (2008) Framing the biosocial pathways underlying associations between place and cardiometabolic disease. *Health Place* 14: 117-132.
6. Voigtlander S, Mielck A, Razum O (2012) [Impact of small-area context on health: proposing a conceptual model]. *Gesundheitswesen* 74: 702-709.
7. Bernard P, Charafeddine R, Frohlich KL, Daniel M, Kestens Y, et al. (2007) Health inequalities and place: a theoretical conception of neighbourhood. *Soc Sci Med* 65: 1839-1852.
8. Robert SA (1999) Socioeconomic Position and Health: The Independent Contribution of Community Socioeconomic Context. *Annu Rev Sociol* 25: 489-516.

9. Schulz AJ, Kannan S, Dvorchak JT, Israel BA, Allen A, et al. (2005) Social and physical environments and disparities in risk for cardiovascular disease: the healthy environments partnership conceptual model. *Environ Health Perspect* 113: 1817-1825.
10. Duncan C, Jones K, Moon G (1998) Context, composition and heterogeneity: using multilevel models in health research. *Soc Sci Med* 46: 97-117.
11. Diez Roux AV (1998) Bringing context back into epidemiology: variables and fallacies in multilevel analysis. *Am J Public Health* 88: 216-222.
12. Diez Roux AV (2002) A glossary for multilevel analysis. *J Epidemiol Community Health* 56: 588-594.
13. Macintyre S, Ellaway A, Cummins S (2002) Place effects on health: how can we conceptualise, operationalise and measure them? *Soc Sci Med* 55: 125-139.
14. Diez Roux AV (2000) Multilevel analysis in public health research. *Annu Rev Public Health* 21: 171-192.
15. Riva M, Gauvin L, Barnett TA (2007) Toward the next generation of research into small area effects on health: a synthesis of multilevel investigations published since July 1998. *J Epidemiol Community Health* 61: 853-861.
16. Sellstrom E, Bremberg S (2006) The significance of neighbourhood context to child and adolescent health and well-being: a systematic review of multilevel studies. *Scand J Public Health* 34: 544-554.
17. Meijer M, Rohl J, Bloomfield K, Grittner U (2012) Do neighborhoods affect individual mortality? A systematic review and meta-analysis of multilevel studies. *Soc Sci Med* 74: 1204-1212.
18. Metcalfe A, Lail P, Ghali WA, Sauve RS (2011) The association between neighbourhoods and adverse birth outcomes: a systematic review and meta-analysis of multi-level studies. *Paediatr Perinat Epidemiol* 25: 236-245.
19. Pickett KE, Pearl M (2001) Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *J Epidemiol Community Health* 55: 111-122.
20. Black JL, Macinko J (2008) Neighborhoods and obesity. *Nutr Rev* 66: 2-20.
21. Mair C, Diez Roux AV, Galea S (2008) Are neighbourhood characteristics associated with depressive symptoms? A review of evidence. *J Epidemiol Community Health* 62: 940-946.
22. Leal C, Chaix B (2011) The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. *Obes Rev* 12: 217-230.
23. Schulz A, Northridge ME (2004) Social determinants of health: Implications for environmental health promotion. *Health Educ Behav* 31: 455-471.
24. Northridge ME, Sclar ED, Biswas P (2003) Sorting out the connections between the built environment and health: A conceptual framework for navigating pathways and planning healthy cities. *J Urban Health* 80: 556-568.
25. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, et al. (2012) Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health* 12: 807.
26. Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS (2010) The built environment and obesity: a systematic review of the epidemiologic evidence. *Health Place* 16: 175-190.
27. Galvez MP, Pearl M, Yen IH (2010) Childhood obesity and the built environment. *Curr Opin Pediatr* 22: 202-207.
28. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE (2011) Neighborhood environment and physical activity among youth a review. *Am J Prev Med* 41: 442-455.

29. Renalds A, Smith TH, Hale PJ (2010) A Systematic Review of Built Environment and Health. *Fam Community Health* 33: 68-78.
30. Bolte G, Pauli A, Hornberg C (2011) Environmental Justice: Social Disparities in Environmental Exposures and Health: Overview. In: Editor-in-Chief: Jerome ON, editor. *Encyclopedia of Environmental Health*. Burlington: Elsevier. pp. 459-470.
31. Krieger N (2001) A glossary for social epidemiology. *J Epidemiol Community Health* 55: 693-700.
32. Krieger N, Williams DR, Moss NE (1997) Measuring social class in US public health research: concepts, methodologies, and guidelines. *Annu Rev Public Health* 18: 341-378.
33. Kirtland KA, Porter DE, Addy CL, Neet MJ, Williams JE, et al. (2003) Environmental measures of physical activity supports: perception versus reality. *Am J Prev Med* 24: 323-331.
34. Ball K, Jeffery RW, Crawford DA, Roberts RJ, Salmon J, et al. (2008) Mismatch between perceived and objective measures of physical activity environments. *Preventive medicine* 47: 294-298.
35. Schaefer-McDaniel N, Caughey MO, O'Campo P, Gearey W (2010) Examining methodological details of neighbourhood observations and the relationship to health: a literature review. *Soc Sci Med* 70: 277-292.
36. Shaw M, Galobardes B, Lawlor DA (2007) *The handbook of inequality and socioeconomic position: concepts and measures*. Bristol: Policy. 238 p.
37. Bell BA, Morgan GB, Kromrey JD, Ferron JM (2010) The Impact of Small Cluster Size on Multilevel Models: A Monte Carlo Examination of Two-Level Models with Binary and Continuous Predictors. *JSM*: 4057-4067.
38. Austin PC (2010) Estimating Multilevel Logistic Regression Models When the Number of Clusters is Low: A Comparison of Different Statistical Software Procedures. *International Journal of Biostatistics* 6.
39. Maas CJM, Hox JJ (2005) Sufficient Sample Sizes for Multilevel Modeling. *Methodology* 1: 86-92.
40. Moineddin R, Matheson FI, Glazier RH (2007) A simulation study of sample size for multilevel logistic regression models. *BMC Med Res Methodol* 7.
41. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ* 339: b2535.
42. Van Dyck D, Cardon G, Deforche B, Owen N, Sallis JF, et al. (2010) Neighborhood Walkability and Sedentary Time in Belgian Adults. *Am J Prev Med* 39: 25-32.
43. Van Dyck D, Cardon G, Deforche B, Sallis JF, Owen N, et al. (2010) Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. *Prev Med* 50 Suppl 1: S74-S79.
44. Riva M, Gauvin L, Apparicio P, Brodeur JM (2009) Disentangling the relative influence of built and socioeconomic environments on walking: the contribution of areas homogenous along exposures of interest. *Social science & medicine* (1982) 69: 1296-1305.
45. Sundquist K, Eriksson U, Kawakami N, Skog L, Ohlsson H, et al. (2011) Neighborhood walkability, physical activity, and walking behavior: The Swedish Neighborhood and Physical Activity (SNAP) study. *Soc Sci Med* 72: 1266-1273.
46. De Meester F, Van Dyck D, De Bourdeaudhuij I, Deforche B, Sallis JF, et al. (2012) Active living neighborhoods: is neighborhood walkability a key element for Belgian adolescents? *BMC public health* 12: 7.

47. Wen M, Zhang X (2009) Contextual effects of built and social environments of urban neighborhoods on exercise: A multilevel study in Chicago. *Am J Health Promot* 23: 247-254.
48. Owen N, Cerin E, Leslie E, duToit L, Coffee N, et al. (2007) Neighborhood walkability and the walking behavior of Australian adults. *Am J Prev Med* 33: 387-395.
49. Moore K, Diez Roux AV, Auchincloss A, Evenson KR, Kaufman J, et al. (2013) Home and work neighbourhood environments in relation to body mass index: the Multi-Ethnic Study of Atherosclerosis (MESA). *Journal of epidemiology and community health* 67: 846-853.
50. Grafova IB, Freedman VA, Kumar R, Rogowski J (2008) Neighborhoods and Obesity in Later Life. *Am J Public Health* 98: 2065-2071.
51. Wang MC, Kim S, Gonzalez AA, MacLeod KE, Winkleby MA (2007) Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. *J Epidemiol Community Health* 61: 491-498.
52. Wen M, Kowaleski-Jones L (2012) The built environment and risk of obesity in the United States: Racial-ethnic disparities. *Health Place* 18: 1314-1322.
53. Ross NA, Tremblay S, Khan S, Crouse D, Tremblay M, et al. (2007) Body mass index in urban Canada: neighborhood and metropolitan area effects. *Am J Public Health* 97: 500-508.
54. Inagami S, Cohen DA, Brown AF, Asch SM (2009) Body mass index, neighborhood fast food and restaurant concentration, and car ownership. *J Urban Health* 86: 683-695.
55. Prince SA, Kristjansson EA, Russell K, Billette J-M, Sawada MC, et al. (2012) Relationships between neighborhoods, physical activity, and obesity: A multilevel analysis of a large Canadian city. *Obesity* 20: 2093-2100.
56. Prince SA, Kristjansson EA, Russell K, Billette JM, Sawada M, et al. (2011) A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada. *International journal of environmental research and public health* 8: 3953-3978.
57. Scott MM, Dubowitz T, Cohen DA (2009) Regional differences in walking frequency and BMI: what role does the built environment play for Blacks and Whites? *Health Place* 15: 882-887.
58. Slater SJ, Ewing R, Powell LM, Chaloupka FJ, Johnston LD, et al. (2010) The association between community physical activity settings and youth physical activity, obesity, and body mass index. *J Adolesc Health* 47: 496-503.
59. Sallis JF, Saelens BE, Frank LD, Conway TL, Slymen DJ, et al. (2009) Neighborhood built environment and income: examining multiple health outcomes. *Soc Sci Med* 68: 1285-1293.
60. Williams BL, Pennock-Roman M, Suen HK, Magsumbol MS, Ozdenerol E (2007) Assessing the impact of the local environment on birth outcomes: a case for HLM. *Journal of exposure science & environmental epidemiology* 17: 445-457.
61. Zeka A, Melly SJ, Schwartz J (2008) The effects of socioeconomic status and indices of physical environment on reduced birth weight and preterm births in Eastern Massachusetts. *Environ Health* 7.
62. Genereux M, Auger N, Goneau M, Daniel M (2008) Neighbourhood socioeconomic status, maternal education and adverse birth outcomes among mothers living near highways. *J Epidemiol Community Health* 62: 695-700.
63. Ponce NA, Hoggatt KJ, Wilhelm M, Ritz B (2005) Preterm birth: The interaction of traffic-related air pollution with economic hardship in Los Angeles neighborhoods. *Am J Epidemiol* 162: 140-148.

64. Reading R, Jones A, Haynes R, Daras K, Emond A (2008) Individual factors explain neighbourhood variations in accidents to children under 5 years of age. *Social science & medicine* (1982) 67: 915-927.
65. Cummins S, Stafford M, Macintyre S, Marmot M, Ellaway A (2005) Neighbourhood environment and its association with self rated health: evidence from Scotland and England. *J Epidemiol Community Health* 59: 207-213.
66. Matthews SA, Yang T-C (2010) Exploring the role of the built and social neighborhood environment in moderating stress and health. *Ann Behav Med* 39: 170-183.
67. Freedman VA, Grafova IB, Rogowski J (2011) Neighborhoods and chronic disease onset in later life. *American journal of public health* 101: 79-86.
68. Freedman VA, Grafova IB, Schoeni RF, Rogowski J (2008) Neighborhoods and disability in later life. *Soc Sci Med* 66: 2253-2267.
69. Stafford M, Cummins S, Macintyre S, Ellaway A, Marmot M (2005) Gender differences in the associations between health and neighbourhood environment. *Social science & medicine* (1982) 60: 1681-1692.
70. Yang TC, Matthews SA (2010) The role of social and built environments in predicting self-rated stress: A multilevel analysis in Philadelphia. *Health & place* 16: 803-810.
71. Chuang YC, Cubbin C, Ahn D, Winkleby MA (2005) Effects of neighbourhood socioeconomic status and convenience store concentration on individual level smoking. *J Epidemiol Community Health* 59: 568-573.
72. Pollack CE, Cubbin C, Ahn D, Winkleby M (2005) Neighbourhood deprivation and alcohol consumption: does the availability of alcohol play a role? *International journal of epidemiology* 34: 772-780.
73. Dragano N, Hoffmann B, Mobus S, Moehlenkamp S, Stang A, et al. (2009) Traffic exposure and subclinical cardiovascular disease: is the association modified by socioeconomic characteristics of individuals and neighbourhoods? Results from a multilevel study in an urban region. *Occup Environ Med* 66: 628-635.
74. Dragano N, Hoffmann B, Stang A, Moebus S, Verde PE, et al. (2009) Subclinical coronary atherosclerosis and neighbourhood deprivation in an urban region. *Eur J Epidemiol* 24: 25-35.
75. Corburn J (2004) Confronting the challenges in reconnecting urban planning and public health. *Am J Public Health* 94: 541-546.
76. deFur PL, Evans GW, Hubal EAC, Kyle AD, Morello-Frosch RA, et al. (2007) Vulnerability as a function of individual and group resources in cumulative risk assessment. *Environ Health Perspect* 115: 817-824.
77. Levy JI (2008) Is Epidemiology the Key to Cumulative Risk Assessment ? *Risk Anal* 28: 1507-1513.
78. Merlo J, Chaix B, Yang M, Lynch J, Rastam L (2005) A brief conceptual tutorial on multilevel analysis in social epidemiology: interpreting neighbourhood differences and the effect of neighbourhood characteristics on individual health. *J Epidemiol Community Health* 59: 1022-1028.
79. Merlo J, Chaix B, Ohlsson H, Beckman A, Johnell K, et al. (2006) A brief conceptual tutorial of multilevel analysis in social epidemiology: using measures of clustering in multilevel logistic regression to investigate contextual phenomena. *J Epidemiol Community Health* 60: 290-297.
80. Tamburlini G (2002) Children's special vulnerability to environmental health hazards: an overview. In: Tamburlini G, von Ehrenstein OS, Bertollini R, editors. *Children's health and environment: a review of evidence A joint report from the European Environment Agency and the WHO Regional Office for Europe Environmental Issue Report No 29*. Copenhagen: European Environment Agency. pp. 18-28.

Table 1. Search terms and Medical Subject Headings in PubMed.

Search	Query
#1	neighborhood [Title/Abstract] OR neighbourhood [Title/Abstract] OR area [Title/Abstract] OR place [Title/Abstract] OR residence [Title/Abstract] OR community [Title/Abstract] OR region [Title/Abstract]
#2	multilevel [Title/Abstract] OR multi-level [Title/Abstract] OR hierarch* [Title/Abstract] OR "multilevel analysis" [MeSH Terms] OR "Small-Area Analysis" [MeSH Terms] OR "mixed effect*" [Title/Abstract] OR "random effect*" [Title/Abstract]
#3	"social environment*" [Title/Abstract] OR socioeconomic [Title/Abstract] OR socio-economic [Title/Abstract] OR sociodemographic [Title/Abstract] or socio-demographic [Title/Abstract] OR "social environment" [MeSH Terms] or "socioeconomic factors" [MeSH Terms]
#4	"physical environment*" [Title/Abstract] OR built [Title/Abstract] OR build* [Title/Abstract] OR "living environment*" [Title/Abstract] OR housing [Title/Abstract] OR pollution [Title/Abstract] OR burden* [Title/Abstract]
Final search	#1 AND #2 AND #3 AND #4

Table 2. Description of studies.

Reference	Health outcomes	Sample	Country	Design	Neighbourhood factors		Individual and further contextual factors considered in multilevel analysis
					Neighbourhood SEP	Objective built environment	
	Physical activity, overweight, quality of life, and depressive symptoms						
De Meester, 2012 [46]	- Average activity level in counts per minute and moderate-to-vigorous physical activity in mean minutes per day assessed with accelerometer (continuous) - Reported walking, cycling, and sport during leisure time, and active transport to and from school in minutes per day (continuous)	Adolescents (13-15 years) N = 637	Belgium	Cross-sectional	Median annual household income	Walkability index (residential density, intersection density, land use mix)	Individual: educational attainment and employment status of parents
Owen, 2007 [48]	- Reported walking for transport in minutes per week and number of days past week (continuous) - Reported walking for recreation in minutes per week and number of days past week (continuous)	Adults (20-65 years) N = 2,650	Australia	Cross-sectional	Median annual household income	Walkability index (dwelling density, street connectivity, land use mix, net retail area)	Individual: age, sex, education, annual household income, children in household, reported reasons for neighbourhood self-selection
Prince, 2012 [55]	- Reported physical activity (dichotomous): inactive and moderately physical activity vs. high physical activity - Under-/normal weight vs. overweight/obesity (dichotomous)	Adults (≥18 years) N = 4,727	Canada	Cross-sectional	Index (households below the low-income cut-off, average household income, unemployed residents, residents with less than a high school education, single-parent families)	Number of winter indoor/outdoor facilities and summer outdoor facilities per 1,000 residents; green space and park area (km ²); bike/walking path length (km); number of grocery stores, fast food outlets, convenience stores, restaurants, and speciality food stores per 1,000 residents	- Individual: age, sex, education, household income, smoking status, season of data collection, community belonging - Contextual: councillor voting rates, crime, season
Prince, 2011 [56]	- Reported physical activity (dichotomous): inactive and moderately physical activity vs. high physical activity - Under-/normal weight vs. overweight/obesity (dichotomous)	Adults (≥18 years) N = 3,514	Canada	Cross-sectional	Index (households below the low-income cut-off, average household income, unemployed residents, residents with less than a high school education, single-parent families)	Number of winter indoor/outdoor facilities and summer outdoor facilities per 1,000 residents; green space and park area (km ²); bike/walking path length (km); number of grocery stores, fast food outlets, convenience stores, restaurants, and speciality food stores per 1,000 residents	- Individual: age, sex, education, household income, smoking status, community belonging - Contextual: councillor voting rates, crime, season
Riva, 2009 [44]	Reported number of 10-minute episodes walking in the last seven days (continuous): walking for any motive, utilitarian walking, recreational walking	Adults (≥45 years) N = 2,923	Canada	Cross-sectional	Percentage of residents with a university education	Urbanity index (population density, land use mix, and accessibility to services)	Individual: age, sex, education
Sallis, 2009 [59]	- Moderate-to-vigorous physical activity in minutes per day assessed with accelerometer (continuous) - Reported walking for leisure and transportation (continuous): minutes per week - BMI (continuous) - Overweight or obesity (dichotomous) - Obesity (dichotomous): - Reported physical quality of life (continuous) - Reported mental quality of life (continuous) - Reported depressive symptoms (continuous)	Adults (20-65 years) N = 2,199	USA	Cross-sectional	Median annual household income	Walkability index (residential density, retail floor area ratio, mixed land use, intersection density)	Individual: age, sex, education, ethnicity, number of adults and motor vehicles in household, marital status, number of people in household, number of years living at current address, reported reasons for moving to neighbourhood
Scott, 2009 [57]	- Reported number of days per week walking to school, to work, to a store, to the bus, to do an errand, or to a neighbour's house (continuous) - Reported number of days per week walking outdoors just for exercise or pleasure (continuous) - BMI (continuous)	Adults (≥18 years) N = 1,815	USA	Cross-sectional	Index (adults older than 25 with less than a high school education, male unemployment, households with income below the poverty line, households receiving public assistance, households with children headed only by a female, median household income)	Number of parks and markets in a one mile radius around home address, street connectivity, median block length, street density	Individual: age, sex, ethnicity, income, access to car in the household, perceived neighbourhood safety, utilitarian and recreational walking considered as an adjustment variables in the final BMI model

Table 2. Continued.

Reference	Health outcomes	Sample	Country	Design	Neighbourhood factors		Individual and further contextual factors considered in multilevel analysis
					Neighbourhood SEP	Objective built environment	
Slater, 2010 [58]	- Reported vigorous exercise (dichotomous) - Reported sports participation (dichotomous) - Reported physical activity participation (dichotomous) - BMI (continuous) - Obesity	Students (13-16 years) N = 10,620 – 36,929	USA	Cross-sectional	Median annual household income	Number of physical activity outlets per 10,000 residents, ratio of higher road classes to all other roads, compactness index (residential density and street connectivity)	- Individual: sex, grade, ethnicity, parental education, student income, students work, mother’s work status, private or public school, region, year of data collection, perceived environment (physical disorder scale, physical activity setting scale, perceived neighbourhood safety) - Contextual: community observations by trained field teams (advertising, recreational space, social interactions, events, safety, general upkeep of the area),
Sundquist, 2011 [45]	- Moderate-to-vigorous physical activity in minutes per day assessed with accelerometer (continuous) - Reported walking for active transportation and leisure (continuous and dichotomous)	Adults (20-66 years) N = 2,269	Sweden	Cross-sectional	Median family income	Walkability index (residential density, street connectivity, land use mix)	Individual: age, sex, family income, marital status
Van Dyck, 2010 [42]	- Sedentary time assessed with accelerometer: percentage of wearing time below 100 counts per minute (continuous) - Reported sitting time in the past 7 days in minutes per day (continuous)	Adults (20-65 years) N = 1,200	Belgium	Cross-sectional	Median annual household income	Walkability index (residential density, street connectivity, land use mix)	Individual: sex, age, education, employment status, occupation, living with children
Van Dyck, 2010 [43]	- Moderate-to-vigorous physical activity in minutes per day assessed with accelerometer (continuous) - Reported walking, recreation, and cycling for transport, and motorized transport in minutes per week (continuous)	Adults (20-65 years) N = 1,166	Belgium	Cross-sectional	Median annual household income	Walkability index (residential density, street connectivity, land use mix)	Individual: age, sex, education, working status, BMI
Wen, 2009 [47]	- Reported number of weekly workout/exercise (dichotomous): one to three times vs. four times or more - Reported regular exercise past year (dichotomous)	Adults (≥18 years) N = 3,530	USA	Cross-sectional	Index (households with an annual income >\$50,000, families below the poverty line, residents ≥25 years with college education, female-headed households, households on public assistance, neighbourly trust, norms of reciprocity, violence)	Distance to subway and parks from the tract centroid; land use mix; number of art centres, cultural institutions, leisure venues, and entertainment facilities in a three-mile buffer from the tract centroid; number of restaurants and bars in a one mile-buffer; number of libraries, churches, and educational institutions in a two-mile buffer; number of health and human services in a three-mile buffer	- Individual: age, sex, ethnicity, marital status, education, household income - Contextual: pedestrian injuries per 100,000 persons, residential density
Inagami, 2009 [54]	BMI (continuous)	Adults (≥18 years) N = 2,156	USA	Cross-sectional	Index (residents below the poverty line, households headed by women, unemployed male residents, families on public assistance)	Number of fast food outlets and number of total food outlets divided by census tract roadway miles	Individual: age, sex, education, ethnicity, employment, marital status, annual household income, immigrant status, car ownership
Moore, 2013 [49]	BMI (continuous)	Adults (45-84 years) N = 1,503	USA	Cross-sectional	Index (Sixteen variables of education, occupation, income, and housing value)	Density of recreational facilities and healthy food environments in a one mile buffer around home address	Individual: age, sex, ethnicity, education, household income, perceived neighbourhood environment (aesthetic quality, walking environment, healthy food availability), perceived neighbourhood safety and social cohesion
Ross, 2007 [53]	BMI (continuous)	Adults (20-64 years) N = 32,964	Canada	Cross-sectional	Percentage of residents with low education, median household income	Dwelling density (dwellings per square kilometre)	- Individual: age, sex, income, education, marital status, smoking status, work-related physical activity, fruit/vegetable consumption, daily stress, immigrant status - Contextual: percentage of recent immigrants
Wang, 2007 [51]	BMI (continuous)	Adults (25-74 years) N = 7,595	USA	Cross-sectional	Index (median family income, median housing value, blue collar workers, unemployed residents, residents having less than high school education)	Total number of stores and fast food restaurants divided by neighbourhood size including a half mile buffer zone around the neighbourhood; proximity to food store or fast food restaurant from home address	Individual: age, sex, ethnicity, individual SEP index (household income and educational attainment), smoking status, physical activity, nutrition knowledge

Table 2. Continued.

Reference	Health outcomes	Sample	Country	Design	Neighbourhood factors		Individual and further contextual factors considered in multilevel analysis
					Neighbourhood SEP	Objective built environment	
Grafova, 2008 [50]	- Under-/normal weight vs. overweight/obesity (dichotomous) - Under-/normal weight vs. obesity (dichotomous)	Adults (≥55 years) N = 15,221	USA	Cross-sectional	- Index I (residents in poverty, residents ≥65 years in poverty, households on public assistance, unemployment rate of residents ≥16 years, housing units without a vehicle, black residents) - Index II (upper quartile value of owner-occupied housing units, families with annual income ≥\$75,000, adults with a college degree)	Street connectivity; number of food stores, restaurants and housing units per square mile and by population density; PM10; summer ozone average	- Individual: age, sex, education, income, ethnicity, marital status, non-housing assets, region of birth, current region, self-rated health as a child, self-rated family SEP as a child, proxy response - Contextual: crime and segregation index, residential stability index, immigrant concentration
Wen, 2012 [52]	Under-/normal weight vs. obesity (dichotomous)	Adults (20-64 years) N = 9,739	USA	Cross-sectional	Index (households with annual income ≥\$75,000, residents living in poverty, college-educated residents)	Street connectivity, distance to closest seven parks from tract centroid	- Individual: age, sex, education, ethnicity, poverty income ratio, smoking status, marital status, US-born - Contextual: Population density, ethnic heterogeneity, percentage of residents walking to work, age of neighbourhood buildings
	Health outcomes and health related behaviours						
Cummins, 2005 [65]	Self-rated health (dichotomous): very good or good health vs. bad or very bad health	Adults (≥16 years) N = 13,899	Britain and Scotland	Cross-sectional	Unemployment index based on claimant count	Food score (number of multiple owned food stores), bank and building society score (banks, building societies and automatic teller machines), health service score (pharmacies, opticians, general practitioners, dental practices), public recreation score (public swimming pools, libraries, and attendance at leisure centres), physical environment score (missed waste collections, public sector housing vacancy rate, vacant and derelict land)	- Individual: age, sex, social class, economic activity - Contextual: transport wealth score (high value cars), private transport score (number of cars per 1,000 population, number of private cars per 1,000 population, number of company cars per 1,000 population), political engagement score (voter turnout), left wing political climate score (political party in power), crime score (sexual/indecent crimes, violent offences, constables/special constables by police force area, spending on police services per capita)
Stafford, 2005 [69]	Self-rated health (dichotomous): very good or good health vs. bad or very bad health	Adults (≥16 years) N = 8,437	Britain and Scotland	Cross-sectional	Unemployment index based on claimant count	Food score (number of Tesco, Sainsbury and Safeway stores), bank and building society score (banks, building societies and automatic teller machines), health service score (pharmacies, opticians, general practitioners), public recreation score (public swimming pools, libraries, and attendance at leisure centres), physical environment score (public sector housing vacancy rate, vacant and derelict land)	- Individual: age, family type, sex, social class, economic activity - Contextual: transport wealth score (high value cars), private transport score (number of private cars per 1,000 population, number of company cars per 1,000 population), political engagement score (voter turnout), political climate score (left-wing political representation), crime score (reported sexual/indecent crimes, spending on police services per capita)
Freedman, 2011 [67]	Reported chronic diseases (dichotomous): heart problems, high blood pressure, stroke, diabetes, cancer, arthritis	Adults (≥55 years) N = 15,374	USA	Cross-sectional	-Index I (residents in poverty, residents ≥65 years in poverty, households receiving public assistance, unemployed residents ≥16 years, housing units without vehicle, black population) -Index II (upper quartile of the percentage of owner-occupied housing units, families with a total annual income of ≥\$75,000, adults with a college degree)	Street connectivity, air pollution (PM10 and summertime ozone averages), density score (food stores, restaurants, housing units, and population density)	- Individual: age, sex, ethnicity, marital status, education, mean assets in \$100,000, income, smoking, region of residence, region of birth, self-rated health and SEP during childhood, proxy response - Contextual: Immigrant concentration, crime and segregation, residential stability
Freedman, 2008 [68]	- Reported body limitations, such as climbing stairs, kneeling, crouching etc. (dichotomous) - Reported limitations of instrumental activities, such as shopping, cooking, etc. (dichotomous) - Reported limitations of daily living activities, such as bathing, dressing, eating etc. (dichotomous)	Adults (≥55 years) N = 15,480	USA	Cross-sectional	-Index I (residents in poverty, residents ≥65 years in poverty, households receiving public assistance, unemployed residents ≥16 years, housing units without a vehicle, black population) -Index II (upper quartile of the percentage of owner-occupied housing units, families with a total annual income of ≥\$75,000, adults with a college degree)	Street connectivity, air pollution (PM10 and summertime ozone averages), density score (density of food stores, restaurants, housing units, and population density)	- Individual: age, sex, ethnicity, marital status, education, income, smoking, current region, region of birth, self-rated health and SEP during childhood, proxy response - Contextual: immigrant concentration, crime and segregation, residential stability

Table 2. Continued.

Reference	Health outcomes	Sample	Country	Design	Neighbourhood factors		Individual and further contextual factors considered in multilevel analysis
					Neighbourhood SEP	Objective built environment	
Matthews, 2010 [66]	Composite health score (continuous): presence of any of six physical health problems and self-rated health (higher values indicate better health)	Adults (≥18 years) N = 4,093	USA	Cross-sectional	- Index I (resident/room ratio, female-headed households, unemployment rate, poverty, people receiving public assistance) - Index II (residents with at least a bachelor's degree, managerial or professional occupations)	Daily vehicle miles travelled, toxic release inventory sites, residual waste operations facilities, medical resources index (licensed and staffed beds, licensed medical doctors, hospitals, patients ≥65 years receiving flu vaccine)	- Individual: age, sex, ethnicity, stress level, marital status, employment status, retired, incapable of working, education, poverty status, religious service attendance, insurance and dental insurance, regular source of care, transportation difficulty in seeing a doctor, neighbourhood participation and trust - Contextual: residential stability, safety index (violent crimes, property crimes, missing persons)
Yang, 2010 [70]	Self-rated day-to-day stress on a scale from 1 to 10 (continuous): higher value indicate more stress	Adults (≥18 years) N = 4,095	USA	Cross-sectional	Index (female headed households, unemployment rate, poverty, residents receiving public assistance, median household income, residents with at least a bachelor's degree)	Daily vehicle miles travelled based on length of road and average daily traffic estimate; toxic release inventory sites and residual waste operation sites	- Individual: age, sex, ethnicity, marital status, employment status, education, poverty, food insecurity, health score (calculated from reported physical health problems and self-rated health), religiosity, trust in neighbourhood people - Contextual: crime, residential stability
Dragano, 2009 [73]	Objective coronary artery calcification (dichotomous)	Adults (45-75 years) N = 4,301	Germany	Cross-sectional	Unemployment rate	Individual distance to major road from home address (>100 m and ≤100 m)	Individual: age, education
Dragano, 2009 [74]	Objective coronary artery calcification (dichotomous)	Adults (45-75 years) N = 4,301	Germany	Cross-sectional	Unemployment rate	Individual distance to major road from home address (0-50 m, 51-100 m, 101-200 m, ≥200 m)	Individual: age, education, economic activity, smoking, physical inactivity, overweight, hypertension, total cholesterol
Chuang, 2005 [71]	Reported number of smoked cigarettes on average per day (continuous)	Adults (25-74 years) N = 8,121	USA	Cross-sectional	Index (residents with less than high school education, blue collar workers, unemployed residents, median annual family income, median housing value)	Number of convenience stores per square mile, individual distance to nearest convenience store from home address, number of convenience stores in a one mile radius around home address	Individual: age, sex, ethnicity, individual SEP index (education, poverty status based on federal poverty threshold)
Pollack, 2005 [72]	Reported alcohol consumption (dichotomous): heavy alcohol consumption (>7 drinks per week for females; >14 drinks per week for males)	Adults (25-74 years) N = 8,197	USA	Cross-sectional	Townsend Material Deprivation Index (crowded occupied housing units, unemployed residents in the civilian labour force, tenant occupied housing units, occupied housing units without a vehicle available)	Number of alcohol outlets per square mile, distance to alcohol outlet from home address, number of alcohol outlets in a half mile radius around home address	Individual: age, sex, ethnicity, marital status, individual SEP index (income and education)
Perinatal and child health							
Généreux, 2008 [62]	- Preterm birth (dichotomous) - Low birth weight (dichotomous) - Small for gestational age (dichotomous)	Life births N = 99,819	Canada	Cross-sectional	Percentage of low-income families	Individual proximity to highway from home address (distance ≤200 m)	Individual: maternal age and education, infant's sex, civil status, maternal country of birth, birth order, history of previous stillbirth, year of birth
Ponce, 2005 [63]	Preterm birth (dichotomous)	Life births N = 37,347	USA	Cross-sectional	Index (unemployed residents in the civilian labour force, households with public assistance income, families with income below the poverty line)	Distance-weighted traffic density based on individual distance to roadways from home address and annual average daily traffic counts	- Individual: Maternal age, education, and ethnicity, payment for delivery, prenatal care, infant's sex, parity, time since previous live birth, previous low birth weight or preterm infant, year of birth, live near highway, air pollutants - Contextual: season
Williams, 2007 [60]	Birth weight in grams (continuous)	Life births N = 13,559	USA	Cross-sectional	Percentage of residents below the poverty level	Average atmospheric concentration of sulphur dioxide, lead and fine particulates around infant's home; number of hazardous waste sites in a 5 kilometre radius around infant's home	Individual: maternal education and ethnicity, infant's sex, previous infant delivery, previous infant >4,000 gram or <37 week, hypertension, oligohydramnios, preeclampsia, previous non-live births, smoking, infants born from same pregnancy, other rare maternal risk factors
Zeka, 2008 [61]	- Birth weight in grams (continuous) - Small for gestational age (dichotomous) - Preterm birth (dichotomous)	Life births N = 425,751	USA	Cross-sectional	Median annual household income	Cumulative average daily traffic; individual distance to major highways from home address; percentage of open space designed for recreation, conversation, water supply, and forestry	Individual: age of mother, maternal education, ethnicity, prenatal visits, gestational age, smoking during pregnancy, previous infant greater than 4,000 gram, previous preterm birth, chronic or gestational conditions of mother, year of birth

Table 2. Continued.

Reference	Health outcomes	Sample	Country	Design	Neighbourhood factors		Individual and further contextual factors considered in multilevel analysis
					Neighbourhood SEP	Objective built environment	
Reading, 2008 [64]	- Reported number of child accidents by mother - Reported number of medical attended child injuries	Children (0-5 years) N = 41,409	Britain	Longitudinal	Percentage of unemployed residents, percentage of social classes 4 and 5	Road density of all roads, road density of major roads, percentage of detached and semi-detached housing, percentage of terraced housing, percentage of purpose built flats, percentage of converted flats	- Individual: child (age, sex, twin or triplet, ethnicity, physical activity, development, behavioural characteristics, motor functions, activity, risk avoidance, strength and difficulties, arguing with mother), mother (age, education, marital status, ethnicity, relationship status, partner moved out, lost partner, employment status, smoking status, alcohol and cannabis consume, depressive symptoms, significant life events, social support), partner (employment status, ethnicity, alcohol consumption), household (number and age of siblings, number of adults, lone parent, number of child caretakers, household income, financial difficulties, home owner, car), housing (rented, flat or room, garden, safety features), perceived neighbourhood environment (quality of neighbourhood, environmental problems, bus traffic, fear of crime, neighbourhood contacts), movement during data collection - Contextual: population aged 0-4 years, lone parents, movements, home owners, renters, overcrowded households, residents without a car, black population
Abbreviations: SEP = Socioeconomic position; BMI = Body Mass Index; PM10 = quarterly measures of particulate matter at 10 µm or less							

Table 3. Associations between socioeconomic and built environments and physical activity.

Reference	Outcomes*	Neighbourhood SEP*				Objective built environment*															Interactions		
		High SEP (Index)	Low SEP (Index)	High Income	High Education	Walk-ability	Urbanity Index	Bike/walking path length	Connectivity	Comp-actness index	Land use mix	Traffic/air pollution	Parks and green space	Sport facilities	Cultural/educational institutions	Restaurants	Fast food outlets	Retail	Health/human services	Dis-tance to parks		Dis-tance to subway	
De Meester, 2012 [46]	Average activity level			M		↔																	⊕ only in low income neighbourhoods
	MVPA			M		↔																	
	Walking, cycling, and sport			n.s.		n.s.																	
	Active transport to and from school			n.s.		n.s.																	
Owen, 2007 [48]	Walking for transport (weekly minutes)			n.s.		↓↑																	⊕ only for people who choose place due to service access
	Walking for transport (weekly frequency)			n.s.		↓↑																	⊕ only for people with 12 or more years of education
	Walking for recreation			n.s.		n.s.																	
Prince, 2012 [55]	Leisure time physical activity		n.s.					n.s.				↓↑	n.s.		n.s.	n.s.	n.s.						⊕ only for women
Prince, 2011 [56]	Overall physical activity		n.s.					n.s.				↓↑ ¹⁾	n.s.		↓↑ ²⁾	n.s.	↓↑ ³⁾						1) ⊖ only for men; 2) ⊕ only for women; 3) ⊕ only for men
Riva, 2009 [44]	Walking per week for any motive				⊕		n.s.																Not reported
	Utilitarian walking per week				⊕		⊕																
	Recreational walking per week				⊕		⊖																
Sallis, 2009 [59]	MVPA			n.s.		⊕																	No significant interactions detected
	Walking for leisure			n.s.		n.s.																	
	Walking for transportation			n.s.		⊕																	
Scott, 2009 [57]	Utilitarian walking	n.s.							n.s.				n.s.					↓↑					⊕ only for non-Hispanic whites
	Recreational walking	n.s.							↓↑				n.s.					n.s.					⊖ only for African Americans (street connectivity (alpha index)) ⊖ stronger for non-Hispanic whites (block length)
Slater, 2010 [58]	Vigorous exercise			n.s.					n.s.			n.s.		n.s.									No significant interactions detected
	Sports participation			n.s.					⊖			n.s.		⊕									
	Physical activity participation			n.s.					n.s.			n.s.		n.s.									

Table 3. Continued.

Reference	Outcomes*	Neighbourhood SEP*				Objective built environment*															Interactions			
		High SEP (Index)	Low SEP (Index)	High Income	High Education	Walk-ability	Urbanity Index	Bike/walking path length	Connectivity	Comp-actness index	Land use mix	Traffic/air pollution	Parks and green space	Sport facilities	Cultural/edu-cational institu-tions	Restau-rants	Fast food outlets	Retail	Health/human services	Dis-tance to parks		Dis-tance to subway		
Sundquist, 2011 [45]	MVPA			n.s.		⊕																	No significant interactions detected	
	Walking for active transportation			n.s.		⊕																		
	Walking for leisure			n.s.		⊕																		
Van Dyck, 2010 [43]	MVPA			n.s.		⊕																	No significant interactions detected	
	Walking for transport			⊖		⊕																		
	Walking for recreation			n.s.		⊕																		
	Cycling for transport			n.s.		⊕																		
	Motorized transport			⊕		⊖																		
Van Dyck, 2010 [42]	Sitting time			n.s.		⊕																	No significant interactions detected	
	Sedentary time			n.s.		⊕																		
Wen, 2009 [47]	Weekly workout/exercise	↓↑									n.s.				n.s.	⊕			n.s.	n.s.	n.s.		⊕ mitigated for men	
	Regular exercise past year	↓↑									n.s.				n.s.	⊕			n.s.	n.s.	n.s.			

* a detailed description of variables is given in table 2

Abbreviations:

SEP = Socioeconomic position; MVPA = Moderate-to-vigorous physical activity; BMI = Body Mass Index; ⊕ = Within-level interaction (interaction is specified in the interaction column); ↓↑ = Cross-level interaction (interaction is specified in the interaction column); ⊕ = Significant positive association; ⊖ = Significant negative association; n.s. = Not significant; M = Variable considered as a moderator via stratification or interaction term

Table 4. Associations between socioeconomic and built environments and measures of overweight.

Reference	Outcomes*	Neighbourhood SEP*					Objective built environment*													Interactions
		High SEP (Index)	Low SEP (Index)	High Income	Low Income	Low Education	Low walkability	Bike/walking path length	Connectivity	Compactness index	Traffic/air pollution	Dwelling density	Density index	Parks and green space	Sport facilities	Distance to parks	Restaurants	Fast food outlets	Retail	
Inagagami, 2009 [54]	BMI		⊕													⊕	↓↑		⊕ mitigated for car owners	
Moore, 2013 [49]	BMI	⊖													⊖			n.s.	Not reported	
Ross, 2007 [53]	BMI			n.s.		⊕					n.s.								No significant interactions detected by sex	
Scott, 2009 [57]	BMI	↓↑							↓↑					↔				n.s.	⊖ only for non-Hispanic whites (alpha index)	
Wang, 2007 [51]	BMI		⊕														n.s.	1) ↔ 2) ↓↑	1) ⊖ only for women (individual proximity to ethnic markets and supermarket); 2) ⊕ only for women (density of grocery stores)	
Slater, 2010 [58]	BMI			⊖					⊖	n.s.				n.s.					No significant interactions detected	
	Obesity			⊖					⊖	n.s.				n.s.						
Sallis, 2009 [59]	BMI				⊕		n.s.												No significant interactions detected	
	Overweight or obesity				n.s.		⊕													
	Obesity				⊕		n.s.													
Grafova, 2008 [50]	Obesity	⊖	n.s.						n.s.	↓↑		n.s.							⊖ only for women (air pollution)	
	Overweight or obesity	⊖	n.s.						n.s.	n.s.		n.s.								
Prince, 2012 [55]	Overweight or obesity		n.s.											↓↑	n.s.		n.s.	↓↑	⊕ only for women	
Prince, 2011 [56]	Overweight or obesity		↓↑ ¹⁾											↓↑ ²⁾	↓↑ ³⁾		⊖	n.s.	↓↑ ⁴⁾	1) ⊖ only for men; 2) ⊕ for men and ⊖ for women; 3) ⊕ only for women (summer outdoor facilities); 4) ⊕ only for women (specialty stores)
Wen, 2012 [52]	Obesity	⊖							⊖							⊕			No significant interactions detected by sex	

* a detailed description of variables is given in table 2

Abbreviations:

SEP = Socioeconomic position; MVPA = Moderate-to-vigorous physical activity; BMI = Body Mass Index; ↔ = Within-level interaction (interaction is specified in the interaction column); ↓↑ = Cross-level interaction (interaction is specified in the interaction column); ⊕ = Significant positive association; ⊖ = Significant negative association; n.s. = Not significant; M = Variable considered as a moderator via stratification or interaction term

Table 5. Associations between socioeconomic and built environments and health outcomes and health-related behaviours.

Reference	Outcomes*	Neighbourhood SEP*				Objective built environment*													Interactions
		Low SEP (Index)	High SEP (Index)	High Income	High unemployment	Walkability	Street connectivity	Traffic/air pollution	Waste sites	Low public recreation score	Low bank/building society score	Low environment score	Low health service score	Density index	Distance to/numbers of stores	Store density	Alcohol outlet density	Low food score	
Cummins, 2005 [65]	Self-rated health				⊕					n.s.	n.s.	↓↑	n.s.					n.s.	⊕ stronger for non-working study participants
Stafford, 2005 [69]	Self-rated health				↓↑ ¹⁾					n.s.	↓↑ ¹⁾	↓↑ ¹⁾	↓↑ ¹⁾					↓↑ ²⁾	1) ⊕ only for women 2) ⊕ only for men
Freedman, 2011 [67]	Heart Problems	↓↑	n.s.				n.s.	n.s.						n.s.					⊕ only for women
	Blood Pressure, Stroke, Cancer Diabetes, Arthritis	n.s.	n.s.				n.s.	n.s.						n.s.					
Freedman, 2008 [68]	Body limitations	n.s.	⊖				n.s.	n.s.						n.s.					
	Daily activity limitations	↓↑	n.s.				n.s.	n.s.						n.s.					⊕ only for men
	Instrumental activity limitations	n.s.	n.s.				n.s.	n.s.						n.s.					
Matthews, 2010 [66]	Health score	⊖	M ↓↑ ¹⁾					⊖	M ↓↑ ²⁾										1) ⊖ for high individual stress: mitigated in more affluent neighbourhoods; 2) ⊖ for high individual stress: stronger in areas with residual waste operations
Sallis, 2009 [59]	Physical quality of life			⊕		n.s.													No significant interactions detected
	Mental quality of life			n.s.		⊖													
	Depressive symptoms			n.s.		⊕													
Yang, 2010 [70]	Day-to-day stress	n.s.						⊕	⊕										Not reported
Dragano, 2009 [73]	Artery calcification				↓↑				M										⊕ only for women with a distance to major road >100 m and ⊕ only for men with a distance to major road <100 m
Dragano, 2009 [74]	Artery calcification				⊕			↔											⊕ only for men with a distance to major roads ≤50 m
Chuang, 2005 [71]	Smoking		↓↑ ¹⁾												↓↑ ^{2); 3)}	↓↑ ⁴⁾ ↔ ⁵⁾			1) ⊖ stronger for high SEP individuals; 2) ⊖ stronger in high SEP neighbourhoods (individual distance to stores); 3) ⊕ stronger in high SEP neighbourhoods (individual number of stores around home address); 4) ⊕ mitigated for high SEP individuals; 5) ⊕ stronger in high SEP neighbourhoods
Pollack, 2005 [72]	Alcohol consumption		⊕														n.s.		No significant within or cross-level interactions detected

* a detailed description of variables is given in table 2

Abbreviations:
 SEP = Socioeconomic position; MVPA = Moderate-to-vigorous physical activity; BMI = Body Mass Index; ↔ = Within-level interaction (interaction is specified in the interaction column); ↓↑ = Cross-level interaction (interaction is specified in the interaction column); ⊕ = Significant positive association; ⊖ = Significant negative association; n.s. = Not significant; M = Variable considered as a moderator via stratification or interaction term

Table 6. Associations between socioeconomic and built environments and perinatal outcomes and child health.

Reference	Outcomes*	Neighbourhood SEP*					Objective built environment*							Interactions	
		SEP Index	High Income	Low income	Unemployment	Poverty	Air pollution	Traffic	Proximity to highways	Distance to highways	Road density	Waste sites	Open space		Building characteristics
Généreux, 2008 [62]	Preterm birth			M					↔↑						⊕ only in neighbourhoods with a high income and for mothers with a university education
	Low birthweight			M					↔↑						⊕ only in neighbourhoods with a high income and for mothers with a university education
	Small for gestational age			M					↓						⊕ only in neighbourhoods with a high income
Ponce, 2005 [63]	Preterm birth	M						↓							⊕ only in low SEP neighbourhoods during winter
Williams, 2007 [60]	Birth weight					↓	⊖					n.s.			⊖ stronger for individuals with rare maternal risk factors
Zeka, 2008 [61]	Birth weight		⊕					n.s.		↔			↓		⊕ only for mothers with a high education
	Small for gestational age		⊖							n.s.			n.s.		
	Preterm birth		n.s.							n.s.			n.s.		
Reading, 2008 [64]	Child accidents and injuries				n.s.						n.s.			n.s.	not analysed

* a detailed description of variables is given in table 2

Abbreviations:

SEP = Socioeconomic position; MVPA = Moderate-to-vigorous physical activity; BMI = Body Mass Index; ↔ = Within-level interaction (interaction is specified in the interaction column); ↓↑ = Cross-level interaction (interaction is specified in the interaction column); ⊕ = Significant positive association; ⊖ = Significant negative association; n.s. = Not significant; M = Variable considered as a moderator via stratification or interaction term

Figure Legends

Figure 1. Flow diagram of study selection.

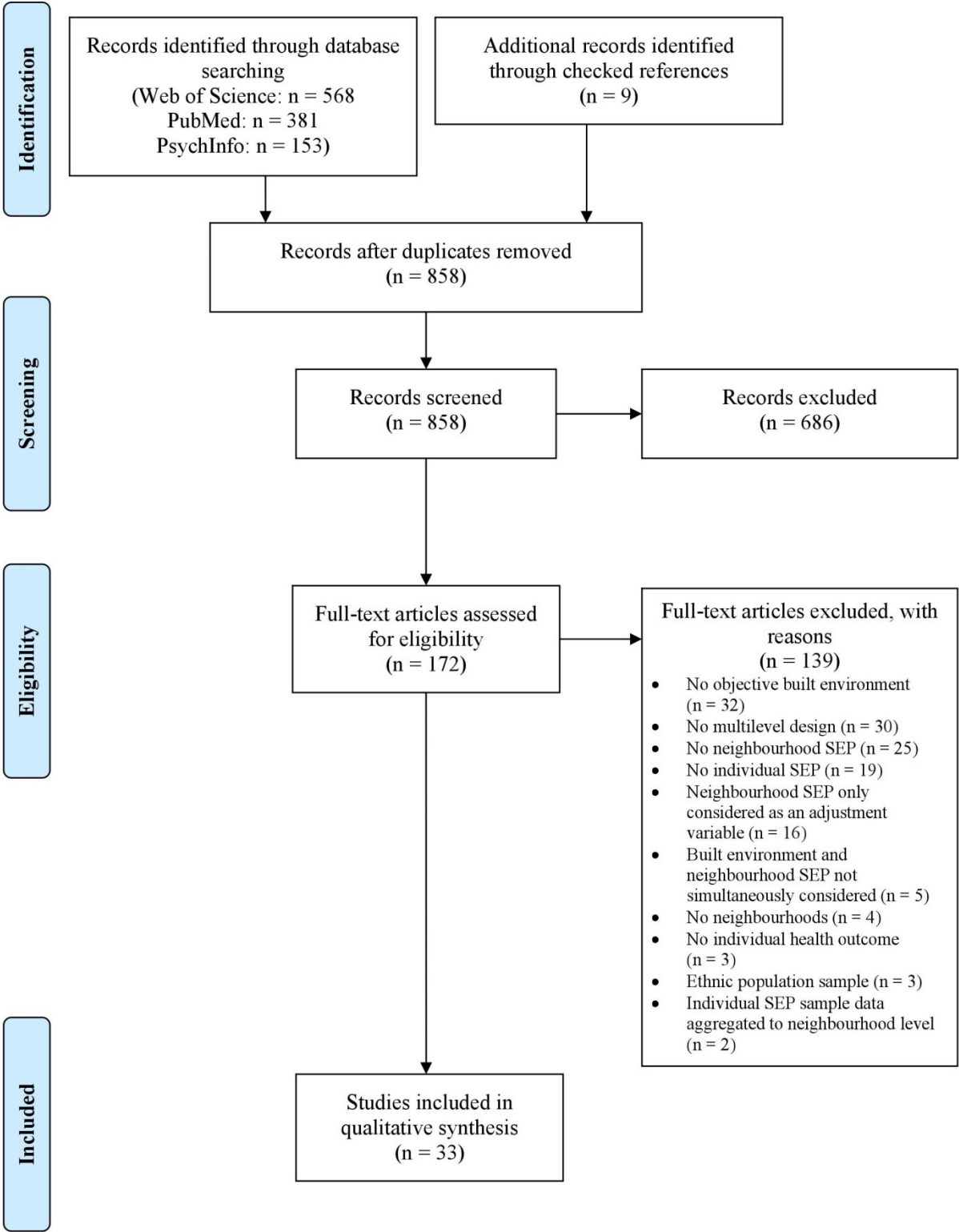
The diagram describes the information flow containing number of identified records, included and excluded records, and the reasons why records were excluded. The diagram was adapted from the PRISMA statements [41].

Supporting Information Legends

Checklist S1. PRISMA 2009 checklist.

Search queries S2. Search terms for PubMed, PsychInfo, and Web of Science.

Figure 1. Flow diagram of study selection.



Checklist S1. PRISMA 2009 checklist.



PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3, 4, 5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5, 6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5, 6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5, 6, table 1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5, 6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	N/A*
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	N/A



PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	N/A
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7, figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7, 8, table 2
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	N/A
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	9-14, tables 3-6
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	N/A
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	N/A
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	14-15
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	15 – 19
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	See financial disclosure/funding

* N/A = Not applicable

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med* 6(6): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: www.prisma-statement.org.

Search queries S2. Search terms for PubMed, PsychInfo, and Web of Science.

PubMed (Advanced search) ¹⁾

(neighborhood [Title/Abstract] OR neighbourhood [Title/Abstract] OR area [Title/Abstract] OR place [Title/Abstract] OR residence [Title/Abstract] OR community [Title/Abstract] OR region [Title/Abstract]) AND (multilevel [Title/Abstract] OR multi-level [Title/Abstract] OR hierarch [Title/Abstract] OR "multilevel analysis" [MeSH Terms] OR "Small-Area Analysis" [MeSH Terms] OR "mixed effect*" [Title/Abstract] OR "random effect*" [Title/Abstract]) AND ("social environment*" [Title/Abstract] OR socioeconomic [Title/Abstract] OR socio-economic [Title/Abstract] OR sociodemographic [Title/Abstract] OR socio-demographic [Title/Abstract] OR "social environment" [MeSH Terms] OR "socioeconomic factors" [MeSH Terms]) AND ("physical environment*" [Title/Abstract] OR built [Title/Abstract] OR build* [Title/Abstract] OR "living environment*" [Title/Abstract] OR housing [Title/Abstract] OR pollution [Title/Abstract] OR burden* [Title/Abstract])*

PsycINFO (Expert search)

((neighborhood OR neighbourhood OR area OR place OR residence OR community OR region) AND (multilevel OR multi-level OR hierarch OR "mixed effect*" OR "random effect*") AND ("social environment*" OR socioeconomic OR socio-economic OR sociodemographic OR socio-demographic) AND ("physical environment*" OR built OR build* OR "living environment*" OR housing OR pollution OR burden*)).ab,hw,id,ot,tc,ti,tm.*

Web of Science (Advanced search)

TS=((neighborhood OR neighbourhood OR area OR place OR residence OR community OR region) AND (multilevel OR multi-level OR hierarch OR "mixed effect*" OR "random effect*") AND ("social environment*" OR socioeconomic OR socio-economic OR sociodemographic OR socio-demographic) AND ("physical environment*" OR built OR build* OR "living environment*" OR housing OR pollution OR burden*))*

1) Medical Subheadings were only available in PubMed and not in the two other database

Annex A.2 Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: a multilevel study in a large German city

Reference:

Schüle, S. A., von Kries, R., Fromme, H., & Bolte, G. (2016). Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: a multilevel study in a large German city. *BMC Obesity*, 3, 25. doi: 10.1186/s40608-016-0106-4

Link to full article:

<https://bmcobes.biomedcentral.com/articles/10.1186/s40608-016-0106-4>

RESEARCH ARTICLE

Open Access



Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: a multilevel study in a large German city

Steffen Andreas Schüle^{1*}, Rüdiger von Kries², Hermann Fromme³ and Gabriele Bolte¹

Abstract

Background: The context of the close neighbourhood environment in which children live has gained increasing attention in epidemiological research. This study aimed to investigate if contextual neighbourhood socioeconomic position (SEP) was independently associated with overweight in young children aged 5–7 years while simultaneously considering a wide range of individual socioeconomic determinants and known risk factors for overweight.

Methods: Objectively measured body mass index (BMI) data from 3499 children (53 % boys and 47 % girls) from three surveys between 2004 and 2007 clustered in 18 school enrolment zones in the city of Munich, Germany, were analysed with hierarchical logistic regression models. An index of neighbourhood SEP was calculated with principal component analysis using aggregated data. Individual socioeconomic data, maternal BMI, and birth weight were collected with parental questionnaires. We analysed how much of the between neighbourhood variance of overweight was attributable to individual factors and how much was explained by neighbourhood SEP.

Results: The prevalence of overweight, including obesity, was 14.1 %. In the final adjusted model low neighbourhood SEP was independently associated with overweight (odds ratio (OR) = 1.42, 95 % confidence interval (CI) = 1.00–2.00) compared to high neighbourhood SEP. On the individual level low parental education (OR = 1.99, 95 % CI = 1.49–2.65) or middle parental education (OR = 1.50, 95 % CI = 1.16–1.95) compared to high parental education and nationality of the child other than German (OR = 1.53, 95 % CI = 1.17–1.99) compared to German nationality were independently associated with overweight.

Conclusions: Whereas individual determinants were the main drivers in explaining between neighbourhood variance, neighbourhood SEP additionally explained differences in overweight between neighbourhoods. Thus, considering neighbourhood context in intervention planning could result in more effective strategies compared to measures only focusing on individual determinants of overweight.

Keywords: Multilevel study, Hierarchical regression, Neighbourhood, Contextual factors, Children, Overweight, Socioeconomic position

* Correspondence: steffen.schuele@uni-bremen.de

¹Department of Social Epidemiology, Institute for Public Health and Nursing Research, University of Bremen, Bremen, Germany

Full list of author information is available at the end of the article



© 2016 Schüle et al. **Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated.

Background

The increase of overweight and obesity in young children in middle and high income countries in recent decades is described as one of the most challenging public health problems [1, 2]. Children being overweight or obese are at greater risk of pulmonary, orthopaedic, neurological, gastroenterological, endocrine, or cardiovascular diseases in their later life [3, 4]. Therefore, a deeper understanding of the causes of overweight in younger ages and the identification of population groups which are mostly affected and need appropriate interventions is of great importance.

Socio-ecological approaches targeting supportive environments are attracting increasing attention for overweight prevention [5]. Therefore, the research question how contextual neighbourhood factors influence overweight in children is of great interest. A contextual effect is present if factors on the neighbourhood level are independently associated with individual health outcomes while possible individual level risk factors are simultaneously considered to avoid an ecological fallacy. To separate out potential contextual effects from individual effects a multilevel modelling approach offers an appropriate analytic strategy [6–8].

Recent reviews provide evidence that a low contextual neighbourhood socioeconomic position (SEP) is a good predictor for negative health outcomes in childhood. There is still a great heterogeneity in neighbourhood studies on how indicators of neighbourhood SEP are operationalized and a comprehensive theory is still missing. Measures of income, education and employment on the level of administrative areas, such as census tracts, are the most often used indicators describing neighbourhood SEP [9–12].

We used the term SEP in this paper as suggested by Krieger et al. [13, 14]. It is defined as a term which combines economic and social resources with prestige-based characteristics which relatively position individuals, households or neighbourhoods in society.

Most studies analysing associations between neighbourhood SEP and child health were conducted in the USA. Moreover, only a minority of studies have analysed how neighbourhood SEP was associated with measures of overweight in younger children while simultaneously taking into account relevant socioeconomic and parental factors on the individual level in order to disentangle their independent associations. There is evidence that parental education and occupation, household income, and household conditions are the most important socioeconomic indicators during childhood [15]. Parental overweight [16] or high birth weight [17] should be additionally considered as important adjustment variables because these factors can confound associations between neighbourhood SEP, individual SEP and overweight in young children.

Therefore, this study aimed to analyse how the socioeconomic context of neighbourhoods was associated with overweight in young children while simultaneously considering indicators of individual SEP in multilevel analysis as well as birth weight and maternal body mass index (BMI) as adjustment variables. A further objective of this study was to determine how much variance of overweight between neighbourhoods was explained by individual factors and how much was attributable to the neighbourhood socioeconomic context.

Methods

Study population and study area

Data collection was performed within the health monitoring units in Bavaria (GME, Gesundheits-Monitoring-Einheiten) which are organized by the Bavarian Health and Food Safety Authority. Main goal of the GMEs is to monitor health status of children in Bavaria. Therefore, in three consecutive years surveys with identical procedures concerning data collection were conducted within the framework of the obligatory school entrance health examination in three rural and three urban study regions. All parents gave their written informed consent. The ethics committee of the Bavarian medical council approved the procedures of data collection before the first survey [18]. There were only slight modifications of the questionnaires between the surveys.

This analysis considered 3499 children aged 5–7 years in one of the GME study regions, the city of Munich. Data were pooled from the three surveys conducted between 2004 and 2007 in Munich. The children were clustered in 18 school enrolment zones with a range of 117 – 331 children per school district. These districts were used as a proxy for the children's close neighbourhood environment.

Measures of overweight

Weight and height were objectively measured by trained staff of the local health authority. Age-specific BMI percentile curves specific for boys and girls, respectively, were used to derive cut-offs for defining children as overweight or obese. We used the International Obesity Task Force (IOTF) cut-off values by Cole et al. [19]. In our analysis the definition of overweight did also include children with obesity.

Individual characteristics from parental questionnaires

We defined three categories of parental education. The highest level of completed education achieved either by the mother or the father was considered. 'High' included a final degree at university or technical college, A-levels, or advanced technical college entrance qualification. 'Middle' included upper secondary school certificate

or adequate graduation. 'Low' included a lower secondary school certificate or no graduation.

Household equivalent income was calculated based on the reported monthly household net income as disposable income after taxes and social transfers weighted for age and number of household members according to the Organization for Economic Co-operation and Development-modified scale [20]. A relative poverty threshold was defined as 60 % of the median household equivalent income in Bavaria [21]. Three income groups were created: 'low' (<60 % of median), 'middle' (60 % of median – median), and 'high' (>median). Due to a high number of missing information on household income in our dataset we created an additional income group 'not indicated' including parents who did not respond on their income in order to avoid selection bias [22].

Parental working status was considered as a binary variable. Unemployment within household was applied if both parents were marginally employed at most. The category employment was applied if one parent was at least part-time employed. A binary variable of single parenthood was created by combining three answers about single parent, family status, and living together with a partner. Only responses showing consistency in all three answers were taken into account [22].

Household crowding was present if there was more than one person per room or less than 20 m² per person available. Nationality of the child was used as an indicator of migration status. Following the rationale of Schenk et al. [23], categories of German nationality and non-German nationality, including dual citizenship, were defined.

Birth weight and BMI of the mother were obtained from parental questionnaires, too. Three categories of birth weight were generated using international cut-offs from the Pediatric Nutrition Surveillance System (PedNSS) by the Centres for Disease Control and Prevention (CDC) [24]: Low (<2500 gram), normal (2500 gram - 4000 gram), and high (>4000 gram). Maternal BMI data were categorized into normal (<25 kg/m²), overweight (25 kg/m² - <30 kg/m²), and obese (≥30 kg/m²).

Neighbourhood socioeconomic variables

We considered five aggregated variables on the level of administrative primary school enrolment zones in which the children live. Averages from the years 2006 and 2007 were calculated. From the city council of Munich we obtained data on foreigners and migration background (percentage of residents with no German citizenship, and percentage of residents with a German citizenship and a migration background), and household data (percentage of single parent households). Data on education were provided by microm GmbH, Neuss, Germany (percentage of households with lower education and with vocational training).

Statistical analysis

All statistical analyses were performed using SAS statistical software package version 9.3 (SAS Institute, Cary, NC, USA).

We performed bivariate logistic regression between socioeconomic neighbourhood variables, individual variables and overweight. All individual variables which were associated with overweight with a Wald's $P < 0.2$ in bivariate logistic regression were included in multivariate analysis. All socioeconomic neighbourhood variables which were associated with overweight with a Wald's $P < 0.2$ were taken into account for principal component analysis (PCA). This cut-off is recommended for initial covariable selection [25].

PCA was used as a statistical procedure for data reduction of correlated variables because it creates non-correlated orthogonal linear combinations explaining the maximum of variance [26]. The first component explains most of the variance and was therefore used as an indicator for the socioeconomic neighbourhood environment. Higher values of the index imply a lower neighbourhood SEP. Spearman rank correlation coefficients between socioeconomic neighbourhood variables used for PCA and the first component were calculated to check how each neighbourhood socioeconomic indicator was represented in the index. Finally, the index was categorized into tertiles (high, middle, and low neighbourhood SEP).

The variance inflation factor (VIF) ($VIF_i = 1/T_i$) was used to assess multicollinearity between the covariables. The VIF is calculated with the tolerance (T) ($T_i = 1 - R_i^2$). R_i^2 is the calculated variance of each covariate associated with all other independent variables. A VIF higher than 10 indicates a serious problem of multicollinearity [27–29].

We applied multilevel logistic regression modelling with school districts as random intercepts to correct for clustering of individuals within the same school district [30]. Our calculated index of neighbourhood SEP was modelled as a 2nd level variable. All individual level variables were considered on the 1st level. Multilevel modelling enables to estimate variance between school districts separately from residual variation between individuals. Thus, this modelling approach makes quantification of overweight variance between neighbourhoods being explained by our calculated neighbourhood SEP index possible. The GLIMMIX procedure in SAS was used for calculating multilevel models.

In a first empty null model only school districts were modelled as random intercepts in order to assess the covariance parameters for the random intercept variance of overweight between school districts. In a second model individual level variables were included to analyse how these variables were associated with overweight, and how much of the variance between school

zones was explained by these factors. In the full third model the index of neighbourhood SEP was added to assess if there was an independent association between neighbourhood SEP and overweight. For multivariate analysis observations with missing values in any independent variable were not taken into account, except for household income. The category 'not indicated' was generated because of a high number of missing values for this variable. For all other variables considered for multivariate analysis the amount of missing values was acceptable ($\leq 7\%$).

Multilevel models were adjusted for the three survey years considering each survey as a dummy variable and maternal BMI and birthweight. For the neighbourhood intercept variance estimates covariance tests were performed and *p*-values and confidence intervals were calculated. Based on the neighbourhood intercept variance estimates we calculated the proportional change in variance (PCV) in percent according to the following equation by Merlo et al. [31, 32]: $PCV = ((V_a - V_b) / V_a) \times 100$. V_a is the between neighbourhood variance of the empty model and V_b is the between neighbourhood variance including covariables, in the individual model and the full model respectively. As a sensitivity analysis, we performed multiple imputation for missing values for household income. Multiple imputation of hierarchical data is still a research area with remaining issues and there is still no standard procedure to pool covariance estimates from the random intercepts [33]. Therefore, we performed multiple imputation for fixed effects only in order to check if estimates differed to our models considering missing values as an additional income category. We applied cumulative logistic regression imputation within the PROC MIANALYZE procedure in SAS which is appropriate for ordinal variables [34–36]. In order to consider our clustered data structure, school zones were taken into account as dummy variables within the imputation procedure.

Results

Characteristics of study population

There were 53 % boys and 47 % girls in the study population. The overall prevalence of overweight, including obesity, was 14.1 %. Sex-specific prevalence was similar in boys (14.0 %) and girls (14.2 %). 8.5 % of the children had a high birth weight and 24.2 % of mothers were overweight or obese. 17.4 % of the parents had a low education. 13.1 % of the families were affected by relative poverty with a household income below 60 % of the median Bavarian equivalent household income. In 6.9 % of households parents were unemployed, 14.4 % reported to be single parents, and 35.5 % of the families were affected by household crowding (Table 1).

Table 1 Characteristics of study population

	N	Percent
Individual Variables		
Overweight (N = 3499)		
Yes	494	14.1
No	3005	85.9
Sex (N = 3499)		
Boys	1856	53.0
Girls	1643	47.0
Nationality of the child (N = 3479)		
Other than German	658	18.9
German	2821	81.1
Birth weight (N = 3499)		
Low (<2.500 gram)	407	11.6
Normal (2.500 gram – 4.000 gram)	2794	79.9
High (>4.000 gram)	298	8.5
BMI mother (N = 3250)		
Normal (<25 kg/m ²)	2464	75.8
Overweight (25 kg/m ² - <30 kg/m ²)	591	18.2
Obese (≥ 30 kg/m ²)	195	6.0
Parental education (N = 3380)		
High	1971	58.3
Middle	822	24.3
Low	587	17.4
Parental working status (N = 3405)		
Unemployment within household	236	6.9
At least one parent employed	3169	93.1
Single parenthood (N = 3435)		
Single parent	493	14.4
Other	2942	85.7
Equivalent household income (N = 3499)		
Low (<60 % Median) ^a	457	13.1
Middle (60 % to Median)	812	23.2
High (>Median)	824	23.6
Not indicated	1406	40.2
Household crowding (N = 3406)		
Yes	1210	35.5
No	2196	64.5
Contextual Variable		
Neighbourhood SEP (N = 3499)		
High	974	27.8
Middle	1150	32.9
Low	1375	39.3

N total number of observations, SEP Socioeconomic position

^aMedian equivalent household income in Bavaria

Principal component analysis and neighbourhood SEP index

On the neighbourhood level, except of the percentage of single parent households, all other four aggregated socio-economic variables were associated with overweight in bivariate logistic regression (Wald's $P < 0.2$) and were therefore used for PCA (results not shown). The four neighbourhood variables percentage of foreigners, percentage of German residents with migration background, percentage of households with lower education, and percentage of households with vocational training were significantly correlated with the neighbourhood SEP index derived from the first principal component. Spearman rank correlation coefficients ranged between 0.69 and 0.97 and had p -values < 0.05 (results not shown). According to our calculated neighbourhood SEP index, 39.3 % of the study population lived in school districts with a low neighbourhood SEP (Table 1).

Multilevel logistic regression

In bivariate logistic regression all variables on the individual level, except sex and single parenthood, were associated with overweight (Wald's $P < 0.2$). Therefore, sex and single parenthood were not included in multivariate analysis. Low parental education, parental unemployment, low household income, household crowding, and a low neighbourhood SEP were associated with children's overweight. Maternal overweight and a high birth weight were associated with overweight, too (Table 2).

Multicollinearity analysis was performed with the neighbourhood SEP index and all eligible individual variables for multivariate analysis. The values of the VIFs showed acceptable values ranging from 1.0 to 1.8 (results not shown).

In the multilevel null model there was a significant random intercept variance of overweight between neighbourhoods (p -value = 0.035) (Table 3). In both multilevel models containing individual level variables only (individual model, Table 3) and neighbourhood SEP additionally (full model, Table 3) low or middle parental education and non-German nationality of the child were positively associated with children's overweight. All other characteristics describing individual socioeconomic position remained not significant. In the full model with neighbourhood SEP as a second level variable a low neighbourhood SEP was positively associated with overweight independent from individual factors.

The full model including neighbourhood SEP explained additional 19.1 % between neighbourhood variance of overweight. However, the neighbourhood intercept variance estimates from which the PCV was calculated showed wide confidence intervals.

Our sensitivity analysis with multiple imputed data for missing values on household income revealed similar estimates for individual variables and contextual

Table 2 Bivariate associations of individual factors and neighbourhood SEP, respectively, with overweight

Variables	OR (95 % CI)	p -value
Sex		
Boy	0.98 (0.81-1.19)	0.8429
Girl	Reference	
Nationality of the child		
Other than German	2.05 (1.65-2.54)	<.0001
German	Reference	
Birth weight		
Low (<2.500 gram)	0.92 (0.67-1.25)	0.5808
Normal (2.500 gram – 4.000 gram)	Reference	
High (>4.000 gram)	1.78 (1.33-2.40)	0.0001
BMI mother		
Normal (<25 kg/m ²)	Reference	
Overweight (25 kg/m ² - <30 kg/m ²)	2.44 (1.93-3.08)	<.0001
Obese (≥30 kg/m ²)	3.08 (2.19-4.34)	<.0001
Parental Education		
Low	2.53 (1.98-3.23)	<.0001
Middle	1.76 (1.39-2.23)	<.0001
High	Reference	
Parental working status		
Unemployment within household	1.63 (1.17-2.27)	0.0042
At least one parent employed	Reference	
Equivalent household income		
Low (<60 % Median) ^a	2.35 (1.69-3.27)	<.0001
Middle (60 % to Median)	1.79 (1.32-2.43)	0.0002
High (>Median)	Reference	
Not indicated	1.68 (1.27-2.22)	0.0003
Single parenthood		
Single parent	1.02 (0.77-1.34)	0.9079
Other	Reference	
Household crowding		
Yes	1.55 (1.27-1.88)	<.0001
No	Reference	
Neighbourhood SEP		
High	Reference	
Middle	1.35 (1.03-1.77)	0.0319
Low	2.00 (1.55-2.56)	<.0001

OR Odds ratio, CI Confidence interval, SEP Socioeconomic position

^aMedian equivalent household income in Bavaria

neighbourhood SEP. Therefore, we reported our multilevel results without multiple imputation of the ordinal income variable because we would like to guarantee valid covariance parameter estimates of our variance components (see methods for further details). Moreover, we analysed potential interactions between our

Table 3 Multivariate associations between individual SEP, neighbourhood SEP and overweight applying multilevel logistic regression ($N = 3125$)

Covariables	Null model	Individual model ^a OR (95 % CI)	Full model ^a OR (95 % CI)
Nationality of the child			
Other than German		1.53 (1.18-1.99)	1.53 (1.17-1.99)
German		Reference	Reference
Parental Education			
Low		2.04 (1.54-2.72)	1.99 (1.49-2.65)
Middle		1.53 (1.18-1.99)	1.50 (1.16-1.95)
High		Reference	Reference
Parental working status			
Unemployment within household		1.20 (0.82-1.77)	1.19 (0.80-1.75)
At least one parent employed		Reference	Reference
Equivalent household income			
Low (<60 % Median) ^b		1.22 (0.82-1.83)	1.18 (0.79-1.77)
Middle (60 % to Median)		1.29 (0.93-1.80)	1.26 (0.90-1.75)
High (>Median)		Reference	Reference
Not indicated		1.14 (0.83-1.58)	1.12 (0.81-1.55)
Household crowding			
Yes		0.94 (0.74-1.20)	0.93 (0.72-1.19)
No		Reference	Reference
Neighbourhood SEP			
High			Reference
Middle			1.01 (0.71-1.46)
Low			1.42 (1.00-2.00)
Measures of variation			
Neighbourhood intercept variance (95 % CI) ^c	0.11 (0.046-0.48)	0.047 (0.015-0.80)	0.026 (0.005-20.37)
Proportional change in variance		-57.3 %	-19.1 %

OR Odds ratio, CI Confidence interval, SEP Socioeconomic position

^aAdjusted for survey year, birth weight, and BMI of mother, ^bMedian equivalent household income in Bavaria, ^cCovariance parameter estimates from random intercepts on the log odds scale

significant fixed estimates of our final model and no significant interactions were detected (results not shown).

Discussion

In our final multilevel model low neighbourhood SEP was independently associated with overweight in young children. However, determinants on the individual level explained most between neighbourhood variance of overweight.

Apart from individual SEP we additionally considered birth weight and maternal BMI which are important risk factors for overweight in young children, too [16, 17]. The association between low neighbourhood SEP and overweight remained significant which strengthened the evidence of an independent impact of neighbourhood SEP on overweight in young children. To the best of our knowledge this is one of the first studies addressing this

research question and additionally considering these two important risk factors in multivariate analysis.

In comparison to our findings previous multilevel studies which analysed the influence of neighbourhood SEP on overweight in younger children found an independent association between neighbourhood socioeconomic factors and overweight, too. A longitudinal study in Canadian children aged 2–11 years found out that a poor neighbourhood context based on household income was associated with increasing BMI independent from individual age, sex, education, income, and family structure [37]. Cross-sectional data from the same study which analysed children and youth from 5 to 17 years detected also higher odds for being overweight in neighbourhoods with a low SEP index calculated with data on unemployment, family income, and education [38].

One study from the USA, which analysed children aged 6–18 years, found a positive association between decreasing neighbourhood median household income and obesity and a negative association between increasing home ownership on the neighbourhood level and obesity independent from individual age, sex and SEP. As a proxy for individual SEP the insurance status was considered [39].

A study from Germany which analysed data from the school entrance examination found a positive association between a high percentage of low educational households in the neighbourhood and overweight in 6-year old children [40]. In comparison to our study, on the individual level only the mother tongue was considered as an indicator for individual SEP.

All multilevel studies we identified did not consider birth weight and parental overweight as potential adjustment variables. Moreover, there were great differences concerning the included socioeconomic factors on the individual level and the age groups being considered. Besides that, most studies considered single socioeconomic neighbourhood factors, such as measures of income, unemployment, or education, and did not combine them into an index.

Multilevel studies investigating the independent influence of neighbourhood SEP on overweight in adolescents found similar results [41–43]. A detailed discussion of these studies would go beyond the scope of this study because our study focused on younger children. Most of these studies we identified were cross-sectional and strengthened the need for longitudinal studies investigating contextual effects of neighbourhood characteristics along the life course from early childhood up to adolescence in order to disentangle individual, family, and neighbourhood relationships.

Our final multilevel model showed that 19.1 % of overweight prevalence between neighbourhoods was explained by neighbourhood SEP and most of the variance was attributed to individual factors (57.3 %). However, these estimates should be interpreted with caution because our neighbourhood intercept variance estimates of our individual and full multilevel model showed wide confidence intervals. In only two of our identified studies variance measures were reported. In the study by Grow et al. socioeconomic neighbourhood context explained around 24 % of overweight variance between neighbourhoods [39], whereas in the study by Lange et al. 40 % of BMI variation between neighbourhoods was explained by neighbourhood unemployment [41]. A systematic review by Sellström & Bremberg [12] identified multilevel studies which studied the impact of neighbourhood factors on child and adolescent health. The review calculated that across studies on average 10 % between neighbourhood variance of the health outcome was explained by

contextual factors. Health outcomes in this review were mainly problem behaviours, child maltreatment, injuries, and birth weight. The number and heterogeneity of considered factors on the individual level and the diversity of socioeconomic neighbourhood indicators on the contextual level could explain the large differences of the calculated variance measures.

There are various conceptual models framing the multidimensional pathways how neighbourhood context influence individual health [44–50]. One hypothesis of all these models is that physical environmental factors mediate the effects of neighbourhood SEP on individual health. In the context of overweight, access and quality of food environments, public resources such as parks or playgrounds, and walkability of the built environment could be such potential mediating neighbourhood factors. One hypothesis derived from the environmental justice framework states that built environmental exposures are social unequally distributed both on the individual and the neighbourhood level (exposure variation by SEP) [51]. There is much evidence that a low SEP is inversely associated with a higher environmental burden [52, 53]. Thus, more studies are needed which investigate underlying mechanisms on the pathway between neighbourhood socioeconomic deprivation and overweight in early childhood.

There are some limitations within our study. One is that our study is cross-sectional. However, for the socioeconomic factors analysed in our study reverse causation is very unlikely. Furthermore, we used administrative school enrolment zones as a proxy for the neighbourhood environment. We were not able to draw inferences to what extent these administrative zones correlate with the perceived and used neighbourhood environment of the children and their parents. Besides that, there were no data available on average household income on the neighbourhood level which is a further socioeconomic indicator often considered in neighbourhood studies. Moreover, we were not able to consider other individual risk factors, such as smoking during pregnancy, breastfeeding, or data on nutrition and physical activity. However, there is evidence at least for Germany that parental overweight, high birth weight and socioeconomic indicators are the main determinants for overweight in early childhood [16], and we were able to consider all these individual determinants in our multilevel model. Finally, for analysing random-slopes and cross-level interactions 18 level 2 units might be too low. Although simulation studies showed that 18 level 2 units may be enough for hierarchical logistic regression modelling [54] our random intercept estimates should be interpreted with caution because they showed wide confidence intervals.

One of the major strengths of our study is that we could provide new evidence for the population group of

younger children because there is still a lack of knowledge how contextual neighbourhood factors influence health in early childhood, especially in Germany. To the best of our knowledge it is one of the first studies for this age group in Germany analysing neighbourhood SEP simultaneously with a wide range of individual socioeconomic indicators and the additional consideration of maternal BMI and birth weight as further important individual risk factors. Our BMI measures for children were derived from objectively measured body weight and height by trained staff, thus no bias occurred because of self-reported measures by the parents.

Conclusions

Our study showed that the socioeconomic context in which young children live was associated with overweight independently from individual overweight determinants. Although individual determinants play a more important role in explaining differences in overweight between neighbourhoods, contextual neighbourhood factors should be additionally taken into account for the identification of vulnerable neighbourhoods and population groups. Public health interventions which consider neighbourhood context could be more effective than interventions targeting only at individual risk factors.

Availability of data and materials

The dataset supporting the results of this article may be requested from the Bavarian Health and Food Safety Authority, steering committee of the health monitoring units in Bavaria, Munich, Germany.

Abbreviations

SEP: socioeconomic position; BMI: body mass index; OR: odds ratio; CI: confidence interval; GME: Gesundheits-Monitoring-Einheiten; IOTF: International Obesity Task Force; PedNSS: Pediatric Nutrition Surveillance System; CDC: Centres for Disease Control and Prevention; PCA: principal component analysis; VF: variance inflation factor; PCV: proportional change in variance.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

SAS performed the statistical analysis and wrote the initial draft of the manuscript. HF and GB participated in the conceptualization of the study, in its design and coordination. RvK, HF and GB helped to draft the manuscript. All authors read and approved the final manuscript.

Authors' information

SAS receives a doctoral scholarship within the framework of the Jufo-Salus (Junior Research Group "The City as a healthy living environment independent of social inequalities") which is funded by the foundation "Fritz und Hildegard Berg- Stiftung" within the "Stifterverband für die Deutsche Wissenschaft e.V.", Essen, Germany.

Acknowledgements

The authors thank all parents for participating in the surveys, Lana Hendrowarsito and Birgit Reineke for data management, the GME Study Group of the first three surveys 2004–07, the Department of Health and

Environment in the city of Munich (Sylvia Kranebitter, Heidi Mayrhofer, Gertraud Rohrhirsch and Brigitte Weise), the Department of Statistic in the city of Munich (Ronald Bauch), and the Jufo-Salus (Junior Research Group "The City as a healthy living environment independent of social inequalities").

Author details

¹Department of Social Epidemiology, Institute for Public Health and Nursing Research, University of Bremen, Bremen, Germany. ²Institute of Social Paediatrics and Adolescent Medicine, Ludwig Maximilian University, Munich, Germany. ³Bavarian Health and Food Safety Authority, Munich, Germany.

Received: 16 May 2015 Accepted: 4 May 2016

Published online: 06 May 2016

References

- Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384(9945):766–81. doi:10.1016/S0140-6736(14)60460-8.
- de Onis M, Blossner M, Borghi E. Global prevalence and trends of overweight and obesity among preschool children. *Am J Clin Nutr*. 2010;92(5):1257–64. doi:10.3945/ajcn.2010.29786.
- Dietz WH. Health consequences of obesity in youth: childhood predictors of adult disease. *Pediatrics*. 1998;101(3 Pt 2):518–25.
- Lobstein T, Baur L, Uauy R. Obesity in children and young people: a crisis in public health. *Obes Rev*. 2004;5 Suppl 1:4–104. doi:10.1111/j.1467-789X.2004.00133.x.
- Sacks G, Swinburn B, Lawrence M. Obesity Policy Action framework and analysis grids for a comprehensive policy approach to reducing obesity. *Obes Rev*. 2009;10(1):76–86. doi:10.1111/j.1467-789X.2008.00524.x.
- Duncan C, Jones K, Moon G. Context, composition and heterogeneity: using multilevel models in health research. *Soc Sci Med*. 1998;46(1):97–117.
- Diez Roux AV. Bringing context back into epidemiology: variables and fallacies in multilevel analysis. *Am J Public Health*. 1998;88(2):216–22. doi:10.2105/AJPH.88.2.216.
- Diez Roux AV. A glossary for multilevel analysis. *J Epidemiol Community Health*. 2002;56(8):588–94. doi:10.1136/jech.56.8.588.
- van Vuuren CL, Reijneveld SA, van der Wal MF, Verhoeff AP. Neighborhood socioeconomic deprivation characteristics in child (0–18 years) health studies: A review. *Health Place*. 2014;29:34–42. doi:10.1016/j.healthplace.2014.05.010.
- Rajaratnam JK, Burke JG, O'Campo P. Maternal and child health and neighborhood context: the selection and construction of area-level variables. *Health Place*. 2006;12(4):547–56. doi:10.1016/j.healthplace.2005.08.008.
- Leventhal T, Brooks-Gunn J. The neighborhoods they live in: The effects of neighborhood residence on child and adolescent outcomes. *Psychol Bull*. 2000;126(2):309–37. doi:10.1037/0033-2909.126.2.309.
- Sellström E, Bremberg S. The significance of neighbourhood context to child and adolescent health and well-being: a systematic review of multilevel studies. *Scand J Public Health*. 2006;34(5):544–54. doi:10.1080/14034940600551251.
- Krieger N, Williams DR, Moss NE. Measuring social class in US public health research: concepts, methodologies, and guidelines. *Annu Rev Public Health*. 1997;18:341–78. doi:10.1146/annurev.publhealth.18.1.341.
- Krieger N. A glossary for social epidemiology. *J Epidemiol Community Health*. 2001;55(10):693–700. doi:10.1136/jech.55.10.693.
- Galobardes B, Shaw M, Lawlor DA, Lynch JW, Davey SG. Indicators of socioeconomic position (part 1). *J Epidemiol Community Health*. 2006;60(1):7–12. doi:10.1136/jech.2004.023531.
- Danielzik S, Czerwinski-Mast M, Langnase K, Dilba B, Muller MJ. Parental overweight, socioeconomic status and high birth weight are the major determinants of overweight and obesity in 5–7 y-old children: baseline data of the Kiel Obesity Prevention Study (KOPS). *Int J Obes Relat Metab Disord*. 2004;28(11):1494–502. doi:10.1038/sj.ijo.0802756.
- Schellong K, Schulz S, Harder T, Plogemann A. Birth weight and long-term overweight risk: systematic review and a meta-analysis including 643,902 persons from 66 studies and 26 countries globally. *PLoS One*. 2012;7(10), e47776. doi:10.1371/journal.pone.0047776.
- Bolte G, Heissenhuber A, von Kries R, Liebl B, Zapf A, Wildner M, et al. Health monitoring units in Bavaria. Concept, aims and thematic focus of the

- first survey on children's environment and health. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz*. 2007;50(4):476–83. doi:10.1007/s00103-007-0191-0.
19. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320(7244):1240–3. doi:10.1136/bmj.320.7244.1240.
 20. Gallie D, Paugam S. Social precarity and social integration. Luxembourg: Office for Official Publications of the European Communities; 2003.
 21. Bayerisches Staatsministerium für Arbeit und Sozialordnung Familie und Frauen. Zweiter Bericht der Staatsregierung zur sozialen Lage in Bayern. München: 2009. http://www.stmas.bayern.de/imperia/md/content/stmas/stmas_internet/sozialpolitik/sozbericht2.pdf. Accessed 6 May 2016.
 22. Scharte M, Bolte G, for the GME Study Group. Increased health risks of children with single mothers: the impact of socio-economic and environmental factors. *Eur J Public Health*. 2013;23(3):469–75. doi:10.1093/eurpub/cks062.
 23. Schenk L, Bau AM, Borde T, Butler J, Lampert T, Neuhauser H, et al. A basic set of indicators for mapping migrant status. Recommendations for epidemiological practice. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz*. 2006;49(9):853–60. doi:10.1007/s00103-006-0018-4.
 24. Pediatric Nutrition Surveillance System (PedNSS) - PedNSS Health Indicators. Centers for Disease Control and Prevention. http://www.cdc.gov/pednss/what_is/pednss_health_indicators.htm. Accessed 6 May 2016.
 25. Hosmer DW, Lemeshow S, Sturdivant RX. *Applied logistic regression*. 3rd ed. Hoboken: Wiley; 2013.
 26. Tabachnick BG, Fidell LS. *Using multivariate statistics*. 6th ed. Boston: Pearson Education; 2013.
 27. Alin A. Multicollinearity. *WIREs Comput Statistics*. 2010;2:370–4. doi:10.1002/wics.84.
 28. Harrell FE. *Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis*. Springer series in statistics. New York: Springer; 2001.
 29. Menard SW. *Applied logistic regression analysis*. In: Sage university papers Quantitative applications in the social sciences, vol no 07–106. 2nd ed. Thousand Oaks, Calif: Sage Publications; 2002.
 30. Wang J, Xie H, Fischer JH. *Multilevel models: applications using SAS*. Berlin, Boston: De Gruyter; Higher Education Press; 2012.
 31. Merlo J, Ohlsson H, Lynch KF, Chaix B, Subramanian SV. Individual and collective bodies: using measures of variance and association in contextual epidemiology. *J Epidemiol Community Health*. 2009;63(12):1043–8. doi:10.1136/jech.2009.088310.
 32. Merlo J, Yang M, Chaix B, Lynch J, Rastam L. A brief conceptual tutorial on multilevel analysis in social epidemiology: investigating contextual phenomena in different groups of people. *J Epidemiol Community Health*. 2005;59(9):729–36. doi:10.1136/jech.2004.023929.
 33. Van Buuren S. Multiple Imputation of Multilevel Data. In: Hox JJ, Roberts JK, editors. *Handbook of Advanced Multilevel Analysis*. New York: Routledge; 2011.
 34. Allison PD. *Imputation of Categorical Variables with PROC M*. Philadelphia, Pennsylvania: SUGI 30 Proceedings; 2005.
 35. Berglund PA. An introduction to multiple imputation of complex sample data using SAS® v9.2 (Paper 265-2010). Seattle, Washington: Proceedings of the SAS Global Forum; 2010.
 36. Ault K. Multiple Imputation for Ordinal Variables: A Comparison of SUDAAN PROC IMPUTE and SAS® PROC MI. Seattle, Washington: 20th Annual SouthEast SAS Users Group (SESUG) Conference; 2012.
 37. Oliver LN, Hayes MV. Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health*. 2008;8:16. doi:10.1186/1471-2458-8-16.
 38. Oliver LN, Hayes MV. Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. *Can J Public Health*. 2005;96(6):415–20.
 39. Grow HM, Cook AJ, Arterburn DE, Saelens BE, Drewnowski A, Lozano P. Child obesity associated with social disadvantage of children's neighborhoods. *Soc Sci Med*. 2010;71(3):584–91. doi:10.1016/j.socscimed.2010.04.018.
 40. Koller D, Mielck A. Regional and social differences concerning overweight, participation in health check-ups and vaccination. Analysis of data from a whole birth cohort of 6-year old children in a prosperous German city. *BMC Public Health*. 2009;9:43. doi:10.1186/1471-2458-9-43.
 41. Lange D, Wahrendorf M, Siegrist J, Plachta-Danielzik S, Landsberg B, Müller MJ. Associations between neighbourhood characteristics, body mass index and health-related behaviours of adolescents in the Kiel Obesity Prevention Study: a multilevel analysis. *Eur J Clin Nutr*. 2011;65(6):711–9. doi:10.1038/Ejcn.2011.21.
 42. Veugelaers PJ, Fitzgerald AL. Prevalence of and risk factors for childhood overweight and obesity. *CMAJ*. 2005;173(6):607–13. doi:10.1503/cmaj.050445.
 43. Janssen I, Boyce WF, Simpson K, Pickett W. Influence of individual- and area-level measures of socioeconomic status on obesity, unhealthy eating, and physical inactivity in Canadian adolescents. *Am J Clin Nutr*. 2006;83(1):139–45.
 44. Diez Roux AV, Mair C. Neighborhoods and health. *Biology of Disadvantage: Socioeconomic Status and Health*. 2010;1186:125–45. doi:10.1111/j.1749-6632.2009.05333.x
 45. Schreier HM, Chen E. Socioeconomic status and the health of youth: a multilevel, multidomain approach to conceptualizing pathways. *Psychol Bull*. 2013;139(3):606–54. doi:10.1037/a0029416.
 46. Chaix B. Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research agenda. *Annu Rev Public Health*. 2009;30:81–105. doi:10.1146/annurev.publhealth.031308.100158.
 47. Daniel M, Moore S, Kestens Y. Framing the biosocial pathways underlying associations between place and cardiometabolic disease. *Health Place*. 2008;14(2):117–32. doi:10.1016/j.healthplace.2007.05.003.
 48. Robert SA. Socioeconomic position and health: the independent contribution of community socioeconomic context. *Annu Rev Sociol*. 1999;25:489–516.
 49. Schulz AJ, Kanan S, Dvonch JT, Israel BA, Allen A, James SA, et al. Social and physical environments and disparities in risk for cardiovascular disease: the healthy environments partnership conceptual model. *Environ Health Perspect*. 2005;113(12):1817–25. doi:10.1289/ehp.7913.
 50. Black JL, Macinko J. Neighborhoods and obesity. *Nutr Rev*. 2008;66(1):2–20. doi:10.1111/j.1753-4887.2007.00001.x.
 51. Bolte G, Pauli A, Hornberg C. Environmental Justice: Social Disparities in Environmental Exposures and Health: Overview. In: Jerome ON, editor. *Encyclopedia of Environmental Health*. Burlington: Elsevier; 2011. p. 459–70.
 52. Bolte G, Tamburini G, Kohlhuber M. Environmental inequalities among children in Europe—evaluation of scientific evidence and policy implications. *Eur J Public Health*. 2010;20(1):14–20. doi:10.1093/eurpub/ckp213.
 53. Brulle RJ, Pellow DN. Environmental justice: human health and environmental inequalities. *Annu Rev Public Health*. 2006;27:103–24. doi:10.1146/annurev.publhealth.27.021405.102124.
 54. Austin PC. Estimating Multilevel Logistic Regression Models When the Number of Clusters is Low: A Comparison of Different Statistical Software Procedures. *Int J Biostatistics*. 2010;6(1). doi:10.2202/1557-4679.1195

Submit your next manuscript to BioMed Central and we will help you at every step:

- We accept pre-submission inquiries
- Our selector tool helps you to find the most relevant journal
- We provide round the clock customer support
- Convenient online submission
- Thorough peer review
- Inclusion in PubMed and all major indexing services
- Maximum visibility for your research

Submit your manuscript at
www.biomedcentral.com/submit



Annex A.3 Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships

Reference:

Schüle, S. A., Fromme, H., & Bolte, G. (2016). Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. *Environmental Research*, 150, 328-336. doi: 10.1016/j.envres.2016.06.024

Link to full article:

<http://www.sciencedirect.com/science/article/pii/S0013935116302596>



Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships



Steffen Andreas Schüle ^{a,*}, Hermann Fromme ^b, Gabriele Bolte ^a

^a Department of Social Epidemiology, Institute for Public Health and Nursing Research, University of Bremen, Bremen, Germany

^b Bavarian Health and Food Safety Authority, Munich, Germany

ARTICLE INFO

Article history:

Received 18 January 2016

Received in revised form

18 May 2016

Accepted 14 June 2016

Keywords:

Multilevel study

Neighbourhood

Contextual factors

Built environment

Children

Overweight

Socioeconomic position

ABSTRACT

Background: Structural factors of neighbourhood environments in which children live have attracted increasing attention in epidemiological research. This study investigated whether neighbourhood socioeconomic position (SEP), public playground and park space, and perceived environmental exposures were independently associated with overweight in preschool aged children while simultaneously considering individual child and family factors.

Methods: Body-Mass-Index (BMI) data from 3499 children (53% boys and 47% girls) from three surveys between 2004 and 2007 from 18 school enrolment zones in the city of Munich, Germany, were analysed with hierarchical logistic regression models. An index of neighbourhood SEP was calculated with principal component analysis. Individual socioeconomic data, parental BMI, birth weight, housing characteristics, and perceived annoyance due to exposures to noise, air pollution, lack of greenspace, and traffic were collected with parental questionnaires. Measures of age-specific playground space and availability of park space derived from Geographic Information System were additionally weighted with age-specific population data.

Results: In bivariate analysis perceived annoyance due to exposures to noise or lack of greenspace, high frequency of lorries, traffic jam, living in a multiple dwelling or next to a main road, low neighbourhood SEP, and low playground space were significantly associated with overweight. However, in multivariate analysis only living in a multiple dwelling was independently associated with overweight. From the considered individual child and family factors low parental education, parental overweight or obesity, and a high birthweight showed an independent relation to overweight.

Conclusions: Our study identified individual child and parental factors, and living in a multiple dwelling as the strongest predictors for overweight in preschool aged children. However, perceived annoyance to built environmental exposures additionally explained overweight variance between neighbourhoods. Based on our findings interventions and policies addressing overweight prevention in young children should focus on parental behaviours and the immediate home environment.

© 2016 Elsevier Inc. All rights reserved.

1. Background

The increasing overweight prevalence in young children in recent decades especially in industrialized countries (de Onis et al., 2010; Ng et al., 2014) has motivated research from various disciplines to gain a better understanding of underlying factors being responsible for this challenging public health problem. There is evidence that both parental factors, such as maternal smoking during pregnancy, not complying with breastfeeding

recommendations, parental overweight, or low parental socioeconomic position (SEP), and individual child factors, such as high birthweight, low physical activity, or too much screen time, are associated with overweight in childhood (Danielzik et al., 2004; Hawkins and Law, 2006; Janssen et al., 2005; Kleiser et al., 2009; Schellong et al., 2012; Shrewsbury and Wardle, 2008).

Apart from individual factors, the consideration of various contextual environmental dimensions and their multiple pathways and interactions towards individual behaviours and child health gained increasing attention (Northridge et al., 2003; Schreier and Chen, 2013; Schulz and Northridge, 2004; Schulz et al., 2005). Socio-ecological approaches and models driven by

* Corresponding author.

E-mail address: steffen.schuele@uni-bremen.de (S.A. Schüle).

Ecological Systems Theory were developed in order to target obesogenic environments (Black and Macinko, 2008; Davison and Birch, 2001; Hawkins and Law, 2006; Sacks et al., 2009; Sallis et al., 2012). Given this framework the research question in epidemiological research how contextual neighbourhood factors of the socioeconomic and built environment have an independent influence on overweight and to what extent they contribute to health inequalities within cities is of great interest.

Systematic reviews provided evidence that structural neighbourhood variables describing neighbourhood SEP are independently associated with child and adolescent health (Leventhal and Brooks-Gunn, 2000; Rajaratnam et al., 2006; Sellström and Bremberg, 2006; van Vuuren et al., 2014). Studies with a particular focus on childhood overweight found an independent association between low neighbourhood SEP and overweight (Grow et al., 2010; Koller and Mielck, 2009; Oliver and Hayes, 2008).

Apart from neighbourhood SEP there are also many studies investigating whether various built environmental factors influence overweight or physical activity in children or adolescents (Berge et al., 2014; Carter and Dubois, 2010; Dunton et al., 2009; Fiechtner et al., 2015; Galvez et al., 2010; Safron et al., 2011). Food environments, physical activity resources, aspects of neighbourhood safety, and features which increase walkability were the main built environmental dimensions which were analysed. The results of these studies were mixed and clear evidence is still lacking.

There is still need for further research for the age group of preschool aged children because most studies looking at adolescents or adults. Moreover, a simultaneous consideration of neighbourhood SEP and built environmental factors in order to disentangle their independent effects is still lacking for this age group (Schüle and Bolte, 2015). Studies differed also widely concerning their adjustment variables which were considered in multivariate analysis. Both parental factors and individual child factors play an important role for this age group and should be additionally taken into account to avoid biased estimates.

This study aimed to analyse how the built and socioeconomic context of neighbourhoods were associated with overweight in preschool aged children. Objective built environmental neighbourhood measures were derived from Geographic Information System (GIS) and perceived environmental measures were assessed with parental questionnaires. Indicators of SEP, birth weight, and parental overweight were simultaneously considered in multilevel analysis. By comparing different multilevel models, we further investigated how much variance of overweight between neighbourhoods was explained by individual factors and how much was attributed to the built and socioeconomic environmental variables.

2. Methods

2.1. Study population and study area

Data collection was performed within the health monitoring units in Bavaria (GME, Gesundheits-Monitoring-Einheiten) which were organized by the Bavarian Health and Food Safety Authority. This analysis considered 3499 children aged 5–7 years taking part in the obligatory school entrance health examination in one of the GME study regions, the city of Munich. Data were pooled from three surveys conducted between 2004 and 2007 in Munich. The children were clustered in 18 school enrolment zones with a range of 117–331 children per school district. These districts were used as a proxy for the children's close neighbourhood environment. The ethics committee of the Bavarian medical council approved

the first GME survey and all parents gave their written consent (Bolte et al., 2007).

2.2. Measures of overweight

Weight and height were objectively measured by trained staff of the local health authority. Age-specific BMI percentile curves specific for boys and girls, respectively, were used to derive cut-offs for defining children as overweight or obese. We used the International Obesity Task Force (IOTF) cut-off values by Cole et al. (2000). In our analysis the definition of overweight also includes children with obesity.

2.3. Individual characteristics from parental questionnaires

We defined three categories of parental education. The highest level of completed education achieved either by the mother or the father was considered. 'High' included a final degree at university or technical college, A-levels, or advanced technical college entrance qualification. 'Middle' included upper secondary school certificate or adequate graduation. 'Low' included a lower secondary school certificate or no graduation.

Household equivalent income was calculated based on the reported monthly household net income as disposable income after taxes and social transfers weighted for age and number of household members according to the Organization for Economic Co-operation and Development-modified scale. A relative poverty threshold was defined as 60% of the median household equivalent income in Bavaria (Bayerisches Staatsministerium für Arbeit und Sozialordnung Familie und Frauen, 2009). Three income groups were created: 'low' (< 60% of median), 'middle' (60% of median–median), and 'high' (> median). Due to a high number of missing information on household income in our dataset we created an additional income group 'not indicated' including parents who did not respond on their income in order to avoid selection bias (Scharte and Bolte, 2013).

Parental working status was considered as a binary variable. The category unemployment within household was applied if both parents were marginally employed at most (less than 15 h per week). The category employment was applied if one parent was at least 15 h per week employed. A binary variable of single parenthood was created by combining three answers about single parent, family status, and living together with a partner. Only responses showing consistency in all three answers were taken into account (Scharte and Bolte, 2013).

Crowding was present if there was more than one person per room or less than 20 m² per person available. Nationality of the child was categorized as German or non-German nationality. A dual citizenship was defined as a non-German nationality.

Three categories of birth weight were generated: Low (< 2500 g), normal (2500–4000 g), and high (> 4000 g). BMI data both from mother and father were categorized into normal (< 25 kg/m²), overweight (25 kg/m²– < 30 kg/m²), and obese (≥ 30 kg/m²).

2.4. Perceived built environmental factors from parental questionnaires

Parents were asked about their annoyance due to exposures to lack of accessible green space and noise and air pollution in their neighbourhood with the following questions: "How strongly do you feel affected by lack of accessible green space in your neighbourhood?", "How strongly do you feel affected by noise pollution in your neighbourhood?", and "How strongly do you feel affected by air pollution in your neighbourhood?". The answers from a five-point Likert scale (no, low, medium, high, very high) were reduced

to a binary variable (no, low vs. medium, high, very high).

The observed frequency of lorries and traffic jam on the road next to their home was assessed with the two following questions: "How often are lorries passing by on the road during weekdays where your child lives?" and "How often do you have slow-moving traffic or traffic jam on the road where your child lives?" The given answers on a four point Likert scale (never, rarely, from time to time per day, almost the whole day) were reduced to a binary variable (never, rarely vs. from time to time per day, almost the whole day).

Parents were able to choose from five road types where their child lives: Main road; side road with no speed limit; side road with speed limit; residential street, play street, or cul-de-sac; no street (such as pedestrian zone). A binary variable was created for analysis (main road vs. other road type).

Parents gave also information on their house type. Originally, five categories were assessed: agricultural residential building, detached house, terrace house or semi-detached house, multiple dwelling up to four floors, multiple dwelling with at least five floors or skyscraper. A binary variable was created for statistical analysis (multiple dwelling up to 4 floors, multiple dwelling with at least five floors or skyscraper vs. other house type).

2.5. Neighbourhood socioeconomic variables

We considered five aggregated variables on the level of administrative primary school enrolment districts describing three aspects of sociodemographic characteristics. From the city council of Munich we got (1) data on foreigners, migration background (percentage of residents with no German citizenship, and percentage of residents with a German citizenship and a migration background), and (2) household characteristics (percentage of single parent households). (3) Data on education and occupation were provided by microm GmbH, Neuss, Germany (percentage of households with lower education and with vocational training). All data were averaged for the years 2006 and 2007.

2.6. Public playground and park space

Data on public playgrounds and parks were provided by the city council of Munich. Data on playgrounds included address, coordinates, and available space for different age groups based on provided facilities. Originally, each playground was categorized into the amount of space for infants (0–5 years), children (5–11 years), or youths (12–15 years). For analysis total playground space for infants and children within each school district was calculated because these age groups were in accordance to our study population. Park space was intersected with school districts and the amount of square meters was calculated with ESRI ArcGIS 10.2.2.

To take into account population characteristics within each school district, the amount of available square meters of playground space for children aged 0–11 years was weighted with the number of residents aged 0–11 years. For park space all residents within each school district were considered for weighting. Age-specific population data from 2004 to 2007 provided by the city council of Munich were averaged and used for population scaling. Finally, the population scaled playground and park variables were each categorized into tertiles (high, middle, and low).

2.7. Statistical analysis

Principal component analysis (PCA) was applied for data reduction of correlated neighbourhood SEP variables (Tabachnick and Fidell, 2013). The first component explains most of the

variance and was therefore used as an indicator for neighbourhood SEP. Higher values of the index imply a lower neighbourhood SEP. Spearman rank correlation coefficients between socioeconomic neighbourhood variables used for PCA and the first component were calculated to check how each neighbourhood socioeconomic indicator was represented in the index. All five socioeconomic neighbourhood variables were represented in the first principal component. Spearman rank correlation coefficients ranged between 0.59 and 0.95 and had p-values < 0.005 (see supplements for detailed results from PCA). Finally, the index was categorized into tertiles (high, middle, and low neighbourhood SEP).

All individual and contextual neighbourhood variables which were associated with overweight with a Wald's P < 0.2 in bivariate logistic regression were included in multivariate analysis (Hosmer et al., 2013). The variance inflation factor (VIF) ($VIF_i = 1/T_i$) was used to assess multicollinearity between the covariables. The VIF is calculated with the tolerance (T) ($T_i = 1 - R_i^2$). R_i^2 is the calculated variance of each covariable associated with all other independent variables. A VIF higher than 10 indicates a serious problem of multicollinearity (Alin, 2010; Harrell, 2001; Menard, 2002).

Multilevel logistic regression modelling was applied to correct for clustering of individuals within the same school district and to estimate variance between school districts separately from residual variation between individuals (Wang et al., 2012). Four multilevel models were calculated: (1) school districts modelled as random intercepts with no covariables in order to assess the area level variance; (2) model 1 plus individual parental and child variables; (3) model 2 plus individual variables on perceived environmental exposures and housing characteristics; (4) model 3 plus contextual neighbourhood SEP, age-specific public playground space, and park availability. The final model was checked for plausible interactions, too.

Comparing the covariance estimates between the four models, we assessed how much variance of overweight between neighbourhoods was explained by individual child and parental variables, by perceived environmental exposures and housing characteristics, and finally by contextual neighbourhood SEP, age-specific public playground space, and park availability. All multilevel models were adjusted for the three survey years considering each survey as a dummy variable.

As area level variance parameter estimates in multilevel logistic regression are difficult to interpret because they are on the log odds scale (Larsen and Merlo, 2005), we calculated the proportional change in variance (PCV) in percent and the median odds ratio (MOR) according to the equations by Merlo et al. (Merlo et al., 2006; Merlo et al., 2005). The PCV is calculated with the formula:

$$PCV = ((V_a - V_b) / V_a) \times 100$$

where V_a is the area level variance parameter estimate of the empty model and V_b is the area level variance parameter estimate including covariables, in the individual models and the full model, respectively. The MOR is calculated with the formula:

$$MOR = \exp\left[\sqrt{(2 \times V_a)}\right] \times 0.6745$$

where V_a is the area level variance parameter estimate of each model. The MOR describes the increased risk in median when an individual would move to another area with higher risks when selecting two areas randomly. A MOR greater than one would indicate area level variations in the probability of being overweight and a MOR equal to one would mean no variation on the area level.

Statistical analysis was performed using SAS statistical software package version 9.3 (SAS Institute, Cary, NC, USA). The GLIMMIX procedure in SAS was applied for multilevel model calculation. Parameter estimation was based on maximum likelihood

estimation with the Laplace method which approximates a marginal log likelihood. This method was selected to ensure unbiased model comparisons because of a true likelihood approximation (Schabenberger, 2007). The Akaike Information Criterion (AIC) (Akaike, 1974) and the Bayesian Information Criterion (BIC) (Schwarz, 1978) were considered to measure the relative goodness of fit.

3. Results

3.1. Characteristics of study population

There were 53% boys and 47% girls in the study population. The overall prevalence of overweight, including obesity, was 14.1%. Sex-specific prevalence was similar in boys (14.0%) and girls (14.2%). 8.5% of the children had a high birth weight, and 24.2% of mothers and 48.9% of fathers were overweight or obese. 17.4% of the parents had a low education, and 13.1% were affected by relative poverty with a household income below 60% of the median Bavarian equivalent household income. In 6.9% of households parents were unemployed, 14.4% reported to be single parents, and 35.5% were affected by crowding (Table 1).

Table 1
Individual parental and child factors.

	N	Percent
Overweight (N=3499)		
Yes	494	14.1
No	3005	85.9
Sex (N=3499)		
Boys	1856	53.0
Girls	1643	47.0
Nationality of the child (N=3479)		
Other than German	658	18.9
German	2821	81.1
Birth weight (N=3499)		
Low (< 2500 g)	407	11.6
Normal (2500–4000 g)	2794	79.9
High (> 4000 g)	298	8.5
BMI mother (N=3250)		
Normal (< 25 kg/m ²)	2464	75.8
Overweight (25 kg/m ² – < 30 kg/m ²)	591	18.2
Obese (≥ 30 kg/m ²)	195	6.0
BMI father (N=2967)		
Normal (< 25 kg/m ²)	1517	51.1
Overweight (25 kg/m ² – < 30 kg/m ²)	1210	40.8
Obese (≥ 30 kg/m ²)	240	8.1
Parental education (N=3380)		
High	1971	58.3
Middle	822	24.3
Low	587	17.4
Parental working status (N=3405)		
Unemployment within household	236	6.9
At least one parent employed	3169	93.1
Single parenthood (N=3435)		
Single parent	493	14.4
Other	2942	85.7
Equivalent household income (N=3499)		
Low (< 60% Median) ^a	457	13.1
Middle (60% to Median)	812	23.2
High (> Median)	824	23.6
Not indicated	1406	40.2
Crowding (N=3406)		
Yes	1210	35.5
No	2196	64.5

N=total number of observations; BMI=Body-Mass-Index.

^a Median equivalent household income in Bavaria.

Table 2

Perceived environmental exposures, housing characteristics, and contextual neighbourhood characteristics.

	N	Percent
Perceived exposures and housing characteristics		
Exposure to noise burden (N=3367)		
Medium/high/very high	670	19.9
No/low	2697	80.1
Exposure to air pollution (N=3332)		
Medium/high/very high	718	21.6
No/low	2614	78.5
Lack of green space in neighbourhood (N=3283)		
Medium/high/very high	521	15.9
No/low	2762	84.1
High frequency of lorries (N=3449)		
From time to time per day/almost the whole day	1035	30.0
Never/rarely	2414	70.0
Traffic jam (N=3451)		
From time to time per day/almost the whole day	409	11.8
Never/rarely	3042	88.2
House type (N=3427)		
Multiple dwelling	2452	71.6
Other (Terrace house, semi-detached house, detached house etc.)	975	28.5
Street type (N=3440)		
Main road	663	19.3
Other (Secondary road, play street, dead-end street etc.)	2777	80.7
Contextual neighbourhood characteristics		
Neighbourhood SEP (N=3499)		
Low	1272	36.4
Middle	1237	35.4
High	990	28.3
Playground space for children 0–11 years (m ² per child 0–11 years old) (N=3499)		
Low (< 43.09 m ²)	1063	30.4
Middle (43.09–93.86 m ²)	1092	31.2
High (> 93.86 m ²)	1344	38.4
Park space (m ² per resident) (N=3499)		
Low (< 1.55 m ²)	1013	29.0
Middle (1.55–4.96 m ²)	1174	33.5
High (> 4.96 m ²)	1312	37.5

N=total number of observations; SEP=Socioeconomic position.

3.2. Parental perception of built environmental exposures and housing characteristics

19.9% of the parents felt annoyed due to exposures to noise burden, 21.6% to air pollution, and 15.9% to lack of green space in their neighbourhood. 30.0% perceived a high frequency of lorries many times per day or the whole day, and 11.8% perceived traffic jam many times per day or the whole day. 71.6% stated to live in a multiple dwelling, and 19.3% assessed that their home is located next to a main road (Table 2).

3.3. Contextual neighbourhood characteristics

According to our calculated neighbourhood SEP index, 36.4% of our study population lived in school districts with a low neighbourhood SEP (Table 2). 30.4% of the children lived in neighbourhoods with 43.09 m² or less of playground space per child specifically designed for children aged 0–11 years, and 29.0% were exposed to a low availability of park space (< 1.55 m² per resident).

3.4. Multilevel logistic regression

In bivariate logistic regression, except of sex and single parenthood, all variables were associated with overweight and had a Wald's P < 0.2 (Table 3). Therefore, sex and single parenthood

Table 3
Unadjusted odds ratios (95% CI) for overweight from bivariate logistic regression.

	OR (95% CI)	p-value
Individual parental and child factors		
Sex		
Boy	0.98 (0.81–1.19)	0.843
Girl	Reference	
Nationality of the child		
Other than German	2.05 (1.65–2.54)	< 0.001
German	Reference	
Birth weight		
Low (< 2500 g)	0.92 (0.67–1.25)	0.581
Normal (2500–4000 g)	Reference	
High (> 4000 g)	1.78 (1.33–2.40)	0.001
BMI mother		
Normal (< 25 kg/m ²)	Reference	
Overweight (25 kg/m ² –lt;30 kg/m ²)	2.44 (1.93–3.08)	< 0.001
Obese (≥ 30 kg/m ²)	3.08 (2.19–4.34)	< 0.001
BMI father		
Normal (< 25 kg/m ²)	Reference	
Overweight (25 kg/m ² – < 30 kg/m ²)	1.97 (1.56–2.48)	< 0.001
Obese (≥ 30 kg/m ²)	3.87 (2.78–5.39)	< 0.001
Parental Education		
Low	2.53 (1.98–3.23)	< 0.001
Middle	1.76 (1.39–2.23)	< 0.001
High	Reference	
Parental working status		
Unemployment within household	1.63 (1.17–2.27)	0.004
At least one parent employed	Reference	
Equivalent household income		
Low (< 60% Median) ^a	2.35 (1.69–3.27)	< 0.001
Middle (60% to Median)	1.79 (1.32–2.43)	< 0.001
High (> Median)	Reference	
Not indicated	1.68 (1.27–2.22)	< 0.001
Single parenthood		
Single parent	1.02 (0.77–1.34)	0.908
Other	Reference	
Crowding		
Yes	1.55 (1.27–1.88)	< 0.001
No	Reference	
Perceived exposures and housing characteristics		
Exposure to noise burden		
Medium/high/very high	1.38 (1.09–1.73)	0.007
No/low	Reference	
Exposure to air pollution		
Medium/high/very high	1.20 (0.96–1.52)	0.101
No/low	Reference	
Lack of green space in neighbourhood		
Medium/high/very high	1.48 (1.16–1.90)	0.002
No/low	Reference	
High frequency of lorries		
From time to time per day/almost the whole day	1.48 (1.21–1.80)	< 0.001
Never/rarely	Reference	
Traffic jam		
From time to time per day/almost the whole day	1.58 (1.21–2.07)	< 0.001
Never/rarely	Reference	
House type		
Multiple dwelling	2.24 (1.74–2.90)	< 0.001
Other (Terrace house, semi-detached house, detached house etc.)	Reference	
Street type		
Main road	1.55 (1.24–1.94)	0.001
Other (Secondary road, play street, dead-end street etc.)	Reference	
Contextual neighbourhood characteristics		
Neighbourhood SEP (N = 3499)		
Low	1.70 (1.33–2.19)	< 0.001
Middle	1.43 (1.11–1.85)	< 0.001
High	Reference	
Playground space for children 0–11 years (m ² per child 0–11 years old)		
Low (< 43.09 m ²)	1.59 (1.26–2.00)	< 0.001
Middle (43.09–93.86 m ²)	1.35 (1.06–1.71)	0.014

Table 3 (continued)

	OR (95% CI)	p-value
High (> 93.86 m ²)	Reference	
Park space (m ² per resident)		
Low (< 1.55 m ²)	1.22 (0.98–1.52)	0.083
Middle (1.55–4.96 m ²)	0.62 (0.48–0.79)	< 0.001
High (> 4.96 m ²)	Reference	

OR=Odds ratio; CI=Confidence interval; BMI=Body-Mass-Index; SEP=Socioeconomic position.

^a Median equivalent household income in Bavaria.

were not included in multivariate analysis. The first multilevel null model with no covariables had a MOR of 1.32 indicating area level variations for individual probability of being overweight (Table 4). In the second model including individual child and parental factors, a high birth weight, parental overweight and obesity, and low or middle parental education were positively associated with children's overweight.

In the third model perceived built environmental exposures and housing characteristics were additionally considered. Only living in a multiple dwelling was positively related to overweight.

In the final model, taking individual and contextual characteristics into account, neighbourhood SEP, age-specific playground space, and public park availability were not independently associated with overweight. All variables which were significantly associated with overweight in the second and third model remained significant. Multicollinearity analysis of the final model showed acceptable values of the VIFs ranging from 1.0 to 2.9 (results not shown).

Comparing the PCV between the four models, individual parental and child factors explained 66.8% of the area level variance. In the third model perceived parental built environmental exposures and housing characteristics explained 21.4% additionally. In the final model the covariance parameter estimate from random intercepts was zero and therefore no differences on the area level concerning probabilities of being overweight exist. Therefore, neighbourhood SEP and playground and park space explained the remaining 11.8% of area level variance.

Both values of the AIC and BIC decreased when individual child and parental factors, perceived built environmental exposures, and housing characteristics were added. In the final model there was no further reduction of AIC and BIC values when contextual neighbourhood characteristics were included.

In order to check our final model for plausible interactions, interaction terms between the significant variables house type and parental education were calculated. None of these interactions were significant (results not shown).

4. Discussion

In the final multilevel level model contextual neighbourhood SEP, age-specific public playground space, and park availability were not independently associated with overweight in preschool aged children whereas on the individual level low and middle parental education, parental overweight or obesity, high birthweight, and living in a multiple dwelling were positively related to overweight.

Individual parental and child factors explained most between neighbourhood variance of overweight (66.8%). Although most of the parentally perceived built environmental exposures and housing characteristics were not independently associated with overweight when further individual factors were taken into

Table 4
Adjusted odds ratios (95% CI) for overweight from multilevel logistic regression (N = 2613).

	Model 1: Null model	Model 2: + Individual parental and child factors ^a	Model 3: + Perceived exposures and housing factors ^a	Model 4: + Neighbourhood factors ^a
Individual parental and child factors				
Nationality of the child				
Other than German		1.31 (0.96–1.78)	1.25 (0.91–1.70)	1.24 (0.91–1.69)
German		Reference	Reference	Reference
Birth weight				
Low (< 2500 g)		0.99 (0.65–1.51)	1.02 (0.67–1.56)	1.02 (0.67–1.56)
Normal (2500–4000 g)		Reference	Reference	Reference
High (> 4000 g)		1.66 (1.15–2.39)	1.73 (1.20–2.49)	1.72 (1.19–2.49)
BMI mother				
Normal (< 25 kg/m ²)		Reference	Reference	Reference
Overweight (25 kg/m ² – < 30 kg/m ²)		2.04 (1.54–2.70)	1.99 (1.50–2.64)	1.98 (1.50–2.63)
Obese (≥ 30 kg/m ²)		2.18 (1.44–3.29)	2.17 (1.44–3.29)	2.15 (1.42–3.25)
BMI father				
Normal (< 25 kg/m ²)		Reference	Reference	Reference
Overweight (25 kg/m ² – < 30 kg/m ²)		1.64 (1.28–2.10)	1.60 (1.23–2.08)	1.59 (1.22–2.08)
Obese (≥ 30 kg/m ²)		2.52 (1.70–3.74)	2.55 (1.72–3.79)	2.54 (1.71–3.77)
Parental Education				
Low		2.11 (1.51–2.93)	1.97 (1.41–2.74)	1.93 (1.38–2.69)
Middle		1.62 (1.21–2.16)	1.54 (1.15–2.06)	1.53 (1.14–2.05)
High		Reference	Reference	Reference
Parental working status				
Unemployment within household		0.86 (0.48–1.55)	0.78 (0.43–1.42)	0.78 (0.43–1.41)
At least one parent employed		Reference	Reference	Reference
Equivalent household income				
Low (< 60% Median) ^b		1.19 (0.75–1.87)	1.14 (0.72–1.80)	1.12 (0.70–1.77)
Middle (60% to Median)		1.28 (0.89–1.82)	1.25 (0.87–1.78)	1.23 (0.86–1.76)
High (> Median)		Reference	Reference	Reference
Not indicated		1.15 (0.81–1.62)	1.14 (0.81–1.62)	1.13 (0.80–1.60)
Crowding				
Yes		0.91 (0.69–1.21)	0.83 (0.63–1.11)	0.83 (0.62–1.10)
No		Reference	Reference	Reference
Perceived exposures and housing characteristics				
Exposure to noise burden				
Medium/high/very high			1.15 (0.77–1.71)	1.13 (0.76–1.67)
No/low			Reference	Reference
Exposure air pollution				
Medium/high/very high			0.74 (0.49–1.11)	0.73 (0.49–1.10)
No/low			Reference	Reference
Lack of green space in neighbourhood				
Medium/high/very high			0.95 (0.67–1.35)	0.94 (0.66–1.32)
No/low			Reference	Reference
High frequency of lorries				
From time to time per day/almost the whole day			1.25 (0.89–1.74)	1.26 (0.90–1.76)
Never/rarely			Reference	Reference
Traffic jam				
From time to time per day/almost the whole day			1.28 (0.83–1.98)	1.28 (0.83–1.97)
Never/rarely			Reference	Reference
House type				
Multiple dwelling			1.79 (1.29–2.48)	1.65 (1.17–2.31)
Other (Terrace house, semi-detached house, detached house etc.)			Reference	Reference
Street type				
Main road			1.10 (0.75–1.62)	1.12 (0.76–1.64)
Other (Secondary road, play street, dead-end street etc.)			Reference	Reference
Contextual neighbourhood characteristics				
Neighbourhood SEP				
Low				1.19 (0.80–1.75)
Middle				1.05 (0.74–1.51)
High				Reference
Playground space for children 0–11 years (m ² per child 0–11 years old)				
Low (< 43.09 m ²)				1.00 (0.64–1.55)
Middle (43.09–93.86 m ²)				0.89 (0.63–1.25)
High (> 93.86 m ²)				Reference
Park space (m ² per resident)				
Low (< 1.55 m ²)				1.19 (0.80–1.75)
Middle (1.55–4.96 m ²)				0.92 (0.66–1.29)
High (> 4.96 m ²)				Reference

Table 4 (continued)

	Model 1: Null model	Model 2: + Individual parental and child factors ^a	Model 3: + Perceived exposures and housing factors ^a	Model 4: + Neighbourhood factors ^a
Measures of variation				
Neighbourhood intercept variance (SE) ^c	0.085 (0.054)	0.0282 (0.036)	0.010 (0.028)	0
Proportional change in variance		–66.8%	–21.4%	–11.8%
Median odds ratio	1.32	1.17	1.1	1.0
Fit statistics				
AIC	1990.40	1887.87	1878.78	1884.19
BIC	1992.18	1903.90	1901.04	1910.90

OR=Odds ratio; CI=Confidence interval; BMI=Body-Mass-Index; SEP=Socioeconomic position; SE=Standard error; AIC=Akaike Information Criterion; BIC=Bayesian Information Criterion.

^a Adjusted for survey year.

^b Median equivalent household income in Bavaria.

^c Covariance parameter estimates from random intercepts on the log odds scale.

account, these factors explained 21.4% between neighbourhood variance additionally. Moreover, their consideration improved the model fit indicated by decreasing AIC and BIC values. Contextual neighbourhood characteristics did not further improve the model fit.

To the best of our knowledge this is one of the first studies considering a wide range of individual child and parental factors simultaneously with subjective environmental exposures, housing characteristics, objective contextual measures of neighbourhood SEP, age-specific playground space, and park availability for preschool aged children.

Our multilevel analysis showed that individual child and family factors played the most important role for overweight in preschool aged children. This result is in accordance with the published literature. A systematic review by Shrewsbury and Wardle identified that low parental education was the most consistent socio-economic indicator which was inversely associated with overweight in childhood (Shrewsbury and Wardle, 2008). Other studies from Germany are also in line with our result: The German Health Interview and Examination Survey for children and adolescents (KiGGS) identified parental overweight and a low SEP, measured with parents' income, education, and occupational status, as the strongest predictors for overweight (Kleiser et al., 2009). A study published by Danielzik et al. (2004) on 5–7 years old children determined parental overweight, low SEP, and a high birthweight as the most important risk factors for these age group, too.

Our findings strengthened the evidence that both perceived and objective measures of built and socioeconomic neighbourhood structures play a minor role for overweight in early childhood. Although there is heterogeneity across existing studies on how built environmental measures were assessed, published studies on preschool aged children which simultaneously considered perceived or objective built environmental characteristics, neighbourhood SEP, and individual child and family factors showed comparable findings.

Hrudey et al. investigated if measures of neighbourhood SEP, perceived satisfaction with green space, safety, and physical disorder (litter, vandalism, graffiti, and dog waste) were associated with overweight in 5–6 year old children. Both neighbourhood SEP and perceived neighbourhood environmental measures had no independent effect when individual family and child factors were included in multilevel analysis (Hrudey et al., 2015).

A study by Hawkins et al. assessed parental perceptions of neighbourhood environments with the additionally consideration of neighbourhood SEP and adjusted for the most important individual risk factors for child overweight, such as birthweight, maternal overweight, smoking during pregnancy, or individual

SEP. Perceived access to retail facilities, overall neighbourhood conditions (noise, rubbish, pollution, and vandalism), overall neighbourhood satisfaction, places where children can play safely, and neighbourhood SEP were not significantly associated with overweight in three year old children. Only children with no access to a private garden were significantly more likely to be overweight than children having access (Hawkins et al., 2009). This association sustains the explanation of our significant house type variable where children living in multiple dwellings had higher odds being overweight than children living in different houses. Most residents in multiple dwellings do not have access to a private garden. As a result, children are limited in performing outdoor physical activity in their immediate home environment. Studies focusing on outdoor play of young children found out that outdoor play was inversely associated with BMI of young children (Kimbrow et al., 2011). Besides that, there is evidence that outdoor physical activity of children happened mostly in a private yard at home (Veitch et al., 2010).

Studies which investigated objective measures of the neighbourhood built environment and their influence on overweight in preschool aged children are consistent with our non-significant associations of age-specific playground space and park availability, even when built environmental measures based on individual home addresses were available in these studies. We could identify only one study which analysed the relationship between public playgrounds and overweight in preschool aged children. Based on distances to playgrounds from individual home addresses Burdette et al. found no independent relation to overweight in 3–5 year old children while simultaneously considering aspects of neighbourhood safety, proximity to fast food restaurants, household income, age, sex, and child's race (Burdette, 2004). Although there were no individual home addresses available in our study, we were able to focus at playground space specifically designed for young children and to take into account age specific population weights of each neighbourhood.

Applying GIS-based methods Potwarka et al. assessed public park availability with a variety of measures. Absolute number of parks within 1 km, park areas within 1 km, and distance to the closest park from the home address were calculated. Multivariate analysis adjusted for sex, age, neighbourhood of residence, and parental BMI revealed no independent association between each of this three park variables and overweight in 2–9 year old children (Potwarka et al., 2008).

Potestio et al. measured spatial access to public parks and recreation areas objectively in four different ways: Total number per 10,000 residents, proportion of park area and park service area in the neighbourhood, and average distance to nearest park from postal code location of the child. The final multilevel model

adjusted for sex, neighbourhood median family income, neighbourhood education, and minorities in the neighbourhood showed no significant association between one of the park variables and overweight in children 3–8 years old (Potestio et al., 2009).

There are also studies investigating the influence of structural neighbourhood factors on overweight of older children. For youth and adolescents findings on how factors of the built environment, such as parks, playground, or sport facilities are related to overweight are mixed (Gose et al., 2013; Lange et al., 2011; Veugelers et al., 2008; Wolch et al., 2011). A detailed discussion of these studies would go beyond the scope of this study. However, such mixed results indicate that there is further need for longitudinal studies investigating contextual effects of neighbourhood characteristics along the life course from early childhood up to adolescence and disentangling individual, family, and neighbourhood relationships.

There are some limitations in our study. Our study is cross-sectional, however, for all factors analysed reverse causation is very unlikely. Moreover, we used administrative school enrolment districts as a proxy for the neighbourhood environment. Based on these administrative areas we calculated our objective GIS-derived measures. However, we were not able to draw inferences how these boundaries correlate with the perceived neighbourhood environment of the parents and their children. Furthermore, our study did not include individual data to what extent parents and children use parks or playgrounds in their living environment and which neighbourhood factors might influence parents and their children to visit public playgrounds (Miles, 2008). Finally, playground and park space data were aggregated to the neighbourhood level because no individual home addresses were available.

One of the major strengths of our study is that we analysed age-specific public playground data. To the best of our knowledge this is one of the first studies considering playground space categorized for different age groups. Moreover, our study considered a wide range of indicators describing SEP both on the individual and neighbourhood level together with further important child and family factors. Finally, our BMI data were objectively measured by trained staff, thus no bias occurred due to self-reported measures.

5. Conclusion

Our study identified that low parental education, parental overweight or obesity, high birthweight, and living in a multiple dwelling were the main risk factors for overweight of preschool aged children whereas contextual neighbourhood SEP, age-specific public playground space, and public park availability showed no independent association with overweight. Although parentally perceived annoyances to built environmental exposures were not independently associated with overweight, these factors additionally explained area level variance of overweight and improved the model fit. Our study sustains recommendations from earlier studies that policies and interventions targeting overweight prevention in early childhood should address parental behaviours and the immediate home environment of the family and their children.

Funding

S.A. Schüle receives a doctoral scholarship within the framework of the Junior Research Group Salus, which is funded by the foundation 'Fritz und Hildegard Berg- Stiftung' (Grant number: T133/22024/2012) within the 'Stifterverband für die Deutsche Wissenschaft e.V.', Essen, Germany. The funders had no role in study design, data collection and analysis, decision to publish, or

preparation of the manuscript. Data collection within the surveys was partly funded by the Bavarian State Ministry of the Environment and Public Health, Munich, Germany.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The authors thank all parents for participating in the surveys, Lana Hendrowarsito and Birgit Reineke for data management, the GME Study group of the first three surveys 2004–2007, the Department of Health and Environment in the city of Munich (Sylvia Kranebitter, Heidi Mayrhofer, Gertraud Rohrhirsch and Brigitte Weise), the Department of Statistic in the city of Munich (Ronald Bauch), the building directorate in the city of Munich (Gabriele Maliska), the Department of city planning and building regulations in the city of Munich (Andreas Peter, Kurt Damaschke), and the Jufo-Salus (Junior Research Group "The City as a healthy living environment independent of social inequalities").

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.envres.2016.06.024>.

References

- Akaike, H., 1974. A new look at the statistical model identification. *IEEE Trans. Autom. Control* 19, 716–723.
- Alin, A., 2010. Multicollinearity. *WIREs Comput. Stat.* 2, 370–374. <http://dx.doi.org/10.1002/wics.84>.
- Bayerisches Staatsministerium für Arbeit und Sozialordnung Familie und Frauen, 2009. Zweiter Bericht der Staatsregierung zur sozialen Lage in Bayern. München.
- Berge, J.M., et al., 2014. Youth dietary intake and weight status: healthful neighborhood food environments enhance the protective role of supportive family home environments. *Health Place* 26, 69–77. <http://dx.doi.org/10.1016/j.healthplace.2013.11.007>.
- Black, J.L., Macinko, J., 2008. Neighborhoods and obesity. *Nutr. Rev.* 66, 2–20. <http://dx.doi.org/10.1111/j.1753-4887.2007.00001.x>.
- Bolte, G., et al., 2007. Health monitoring units in Bavaria. Concept, aims and thematic focus of the first survey on children's environment and health. *Bundesgesundheitsbl. Gesundheitsforsch. Gesundheitsschutz* 50, 476–483. <http://dx.doi.org/10.1007/s00103-007-0191-0>.
- Burdette, H., 2004. Neighborhood playgrounds, fast food restaurants, and crime: relationships to overweight in low-income preschool children. *Prev. Med.* 38, 57–63. <http://dx.doi.org/10.1016/j.ypmed.2003.09.029>.
- Carter, M.A., Dubois, L., 2010. Neighbourhoods and child adiposity: a critical appraisal of the literature. *Health Place* 16, 616–628. <http://dx.doi.org/10.1016/j.healthplace.2009.12.012>.
- Cole, T.J., et al., 2000. Establishing a standard definition for child overweight and obesity worldwide: international survey. *B. Med. J.* 320, 1240–1243. <http://dx.doi.org/10.1136/bmj.320.7244.1240>.
- Danielzik, S., et al., 2004. Parental overweight, socioeconomic status and high birth weight are the major determinants of overweight and obesity in 5–7 y-old children: baseline data of the Kiel Obesity Prevention Study (KOPS). *Int. J. Obes. Relat. Metab. Disord.* 28, 1494–1502. <http://dx.doi.org/10.1038/sj.ijo.0802756>.
- Davison, K.K., Birch, L.L., 2001. Childhood overweight: a contextual model and recommendations for future research. *Obes. Rev.* 2, 159–171. <http://dx.doi.org/10.1046/j.1467-789x.2001.00036.x>.
- Dunton, G.F., et al., 2009. Physical environmental correlates of childhood obesity: a systematic review. *Obes. Rev.* 10, 393–402. <http://dx.doi.org/10.1111/j.1467-789X.2009.00572.x>.
- Fiechtner, L., et al., 2015. Food environments and childhood weight status: effects of neighborhood median income. *Child. Obes.* 11, 260–268. <http://dx.doi.org/10.1089/chi.2014.0139>.
- Galvez, M.P., et al., 2010. Childhood obesity and the built environment. *Curr. Opin. Pediatr.* 22, 202–207. <http://dx.doi.org/10.1097/MOP.0b013e3283336eb6f>.

- Gose, M., et al., 2013. Longitudinal influences of neighbourhood built and social environment on children's weight status. *Int. J. Environ. Res. Public Health* 10, 5083–5096. <http://dx.doi.org/10.3390/ijerph10105083>.
- Grow, H.M., et al., 2010. Child obesity associated with social disadvantage of children's neighborhoods. *Soc. Sci. Med.* 71, 584–591. <http://dx.doi.org/10.1016/j.socscimed.2010.04.018>.
- Harrell, F.E., 2001. *Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis*. Springer, New York.
- Hawkins, S.S., et al., 2009. Perceived and objective measures of the neighbourhood environment and overweight in preschool children and their mothers. *Int. J. Pediatr. Obes.* 4, 183–192. <http://dx.doi.org/10.1080/17477160802596155>.
- Hawkins, S.S., Law, C., 2006. A review of risk factors for overweight in preschool children: a policy perspective. *Int. J. Pediatr. Obes.* 1, 195–209.
- Hosmer, D.W., et al., 2013. *Applied Logistic Regression*, 3rd ed. Wiley, Hoboken.
- Hrudey, E.J., et al., 2015. Do neighborhood characteristics in Amsterdam influence adiposity at preschool age? *Int. J. Environ. Res. Public Health* 12, 5561–5580. <http://dx.doi.org/10.3390/ijerph120505561>.
- Janssen, I., et al., 2005. Comparison of overweight and obesity prevalence in school-aged youth from 34 countries and their relationships with physical activity and dietary patterns. *Obes. Rev.* 6, 123–132. <http://dx.doi.org/10.1111/j.1467-789X.2005.00176.x>.
- Kimbrow, R.T., et al., 2011. Young children in urban areas: links among neighborhood characteristics, weight status, outdoor play, and television watching. *Soc. Sci. Med.* 72, 668–676. <http://dx.doi.org/10.1016/j.socscimed.2010.12.015>.
- Kleiser, C., et al., 2009. Potential determinants of obesity among children and adolescents in Germany: results from the cross-sectional KiGGS Study. *BMC Public Health* 9, 46. <http://dx.doi.org/10.1186/1471-2458-9-46>.
- Koller, D., Mielck, A., 2009. Regional and social differences concerning overweight, participation in health check-ups and vaccination. Analysis of data from a whole birth cohort of 6-year old children in a prosperous German city. *BMC Public Health* 9, 43. <http://dx.doi.org/10.1186/1471-2458-9-43>.
- Lange, D., et al., 2011. Associations between neighbourhood characteristics, body mass index and health-related behaviours of adolescents in the Kiel Obesity Prevention Study: a multilevel analysis. *Eur. J. Clin. Nutr.* 65, 711–719. <http://dx.doi.org/10.1038/Ejcn.2011.21>.
- Larsen, K., Merlo, J., 2005. Appropriate assessment of neighborhood effects on individual health: integrating random and fixed effects in multilevel logistic regression. *Am. J. Epidemiol.* 161, 81–88. <http://dx.doi.org/10.1093/aje/kwi017>.
- Leventhal, T., Brooks-Gunn, J., 2000. The neighborhoods they live in: the effects of neighborhood residence on child and adolescent outcomes. *Psychol. Bull.* 126, 309–337. <http://dx.doi.org/10.1037/0033-2909.126.2.309>.
- Menard, S.W., 2002. *Applied Logistic Regression Analysis*, 2nd ed. Sage Publications, Thousand Oaks, CA.
- Merlo, J., et al., 2005. A brief conceptual tutorial on multilevel analysis in social epidemiology: investigating contextual phenomena in different groups of people. *J. Epidemiol. Community Health* 59, 729–736. <http://dx.doi.org/10.1136/jech.2004.023929>.
- Merlo, J., et al., 2006. A brief conceptual tutorial of multilevel analysis in social epidemiology: using measures of clustering in multilevel logistic regression to investigate contextual phenomena. *J. Epidemiol. Community Health* 60, 290–297. <http://dx.doi.org/10.1136/jech.2004.029454>.
- Miles, R., 2008. Neighborhood disorder, perceived safety, and readiness to encourage use of local playgrounds. *Am. J. Prev. Med.* 34, 275–281. <http://dx.doi.org/10.1016/j.amepre.2008.01.007>.
- Ng, M., et al., 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 384, 766–781. [http://dx.doi.org/10.1016/S0140-6736\(14\)60460-8](http://dx.doi.org/10.1016/S0140-6736(14)60460-8).
- Northridge, M.E., et al., 2003. Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities. *J. Urban Health* 80, 556–568. <http://dx.doi.org/10.1093/jurban/jtg064>.
- Oliver, L.N., Hayes, M.V., 2008. Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health* 8, 16. <http://dx.doi.org/10.1186/1471-2458-8-16>.
- de Onis, M., et al., 2010. Global prevalence and trends of overweight and obesity among preschool children. *Am. J. Clin. Nutr.* 92, 1257–1264. <http://dx.doi.org/10.3945/ajcn.2010.29786>.
- Potestio, M.L., et al., 2009. Is there an association between spatial access to parks/green space and childhood overweight/obesity in Calgary. *Can. Int. J. Behav. Nutr. Phys. Act.* 6, 77. <http://dx.doi.org/10.1186/1479-5868-6-77>.
- Potwarka, L.R., et al., 2008. Places to play: association of park space and facilities with healthy weight status among children. *J. Community Health* 33, 344–350. <http://dx.doi.org/10.1007/s10900-008-9104-x>.
- Rajaratnam, J.K., et al., 2006. Maternal and child health and neighborhood context: the selection and construction of area-level variables. *Health Place* 12, 547–556. <http://dx.doi.org/10.1016/j.healthplace.2005.08.008>.
- Sacks, G., et al., 2009. Obesity Policy Action framework and analysis grids for a comprehensive policy approach to reducing obesity. *Obes. Rev.* 10, 76–86. <http://dx.doi.org/10.1111/j.1467-789X.2008.00524.x>.
- Safron, M., et al., 2011. Micro-environmental characteristics related to body weight, diet, and physical activity of children and adolescents: a systematic umbrella review. *Int. J. Environ. Health Res.* 21, 317–330. <http://dx.doi.org/10.1080/09603123.2011.552713>.
- Sallis, J.F., et al., 2012. Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation* 125, 729–737. <http://dx.doi.org/10.1161/CIRCULATIONAHA.110.969022>.
- Schüle, S.A., Bolte, G., 2015. Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: a systematic review of multilevel studies. *PLoS One*, 10. <http://dx.doi.org/10.1371/journal.pone.0123456>.
- Schabenberger, O., 2007. Growing Up Fast: SAS 9.2 Enhancements to the GLIMMIX procedure. In: *Proceedings of the SAS Global Forum 2007* (Paper 177-2007).
- Scharte, M., Bolte, G., for the GME Study Group, 2013. Increased health risks of children with single mothers: the impact of socio-economic and environmental factors. *Eur. J. Public Health* 23, 469–475. <http://dx.doi.org/10.1093/eurpub/cks062>.
- Schellong, K., et al., 2012. Birth weight and long-term overweight risk: systematic review and a meta-analysis including 643,902 persons from 66 studies and 26 countries globally. *PLoS One* 7, e47776. <http://dx.doi.org/10.1371/journal.pone.0047776>.
- Schreier, H.M., Chen, E., 2013. Socioeconomic status and the health of youth: a multilevel, multidomain approach to conceptualizing pathways. *Psychol. Bull.* 139, 606–654. <http://dx.doi.org/10.1037/a0029416>.
- Schulz, A., Northridge, M.E., 2004. Social determinants of health: implications for environmental health promotion. *Health Educ. Behav.* 31, 455–471. <http://dx.doi.org/10.1177/1090198104265598>.
- Schulz, A.J., et al., 2005. Social and physical environments and disparities in risk for cardiovascular disease: the healthy environments partnership conceptual model. *Environ. Health Perspect.* 113, 1817–1825. <http://dx.doi.org/10.1289/ehp.7913>.
- Schwarz, G., 1978. Estimating the dimension of a model. *Ann. Stat.* 6, 461–464.
- Sellström, E., Bremberg, S., 2006. The significance of neighbourhood context to child and adolescent health and well-being: a systematic review of multilevel studies. *Scand. J. Public Health* 34, 544–554. <http://dx.doi.org/10.1080/14034940600551251>.
- Shrewsbury, V., Wardle, J., 2008. Socioeconomic status and adiposity in childhood: a systematic review of cross-sectional studies 1990–2005. *Obesity* 16, 275–284. <http://dx.doi.org/10.1038/oby.2007.35>.
- Tabachnick, B.G., Fidell, L.S., 2013. *Using Multivariate Statistics*, 6th ed. Pearson Education, Boston.
- van Vuuren, C.L., et al., 2014. Neighborhood socioeconomic deprivation characteristics in child (0–18 years) health studies: a review. *Health Place* 29, 34–42. <http://dx.doi.org/10.1016/j.healthplace.2014.05.010>.
- Veitch, J., et al., 2010. Individual, social and physical environmental correlates of children's active free-play: a cross-sectional study. *Int. J. Behav. Nutr. Phys. Act.* 7, 11. <http://dx.doi.org/10.1186/1479-5868-7-11>.
- Veugelaers, P., et al., 2008. Neighborhood characteristics in relation to diet, physical activity and overweight of Canadian children. *Int. J. Pediatr. Obes.* 3, 152–159. <http://dx.doi.org/10.1080/17477160801970278>.
- Wang, J., et al., 2012. *Multilevel Models: Applications Using SAS*. De Gruyter, Higher Education Press, Berlin and Boston.
- Wolch, J., et al., 2011. Childhood obesity and proximity to urban parks and recreational resources: a longitudinal cohort study. *Health Place* 17, 207–214. <http://dx.doi.org/10.1016/j.healthplace.2010.10.001>.

Annex A.4 Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: an environmental inequality analysis in a large German city applying generalized linear models

Reference:

Schüle, S. A., Gabriel, K.M.A., & Bolte, G. (2017). Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: an environmental inequality analysis in a large German city applying generalized linear models. *International Journal of Hygiene and Environmental Health*, 220(4), 711-718. doi: 10.1016/j.ijheh.2017.02.006

Link to full article:

<http://www.sciencedirect.com/science/article/pii/S1438463916302632>



Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: An environmental inequality analysis in a large German city applying generalized linear models

Steffen Andreas Schüle^{a,b,*}, Katharina M.A. Gabriel^{a,b}, Gabriele Bolte^{a,b}^a University of Bremen, Institute for Public Health and Nursing Research, Department of Social Epidemiology, Germany^b Health Sciences Bremen, University of Bremen, Germany

ARTICLE INFO

Article history:

Received 26 August 2016

Received in revised form 24 February 2017

Accepted 24 February 2017

Keywords:

Green space

Neighbourhood

Environmental justice

Generalized linear models

Health inequalities

Environmental inequalities

ABSTRACT

Background: The environmental justice framework states that besides environmental burdens also resources may be social unequally distributed both on the individual and on the neighbourhood level. This ecological study investigated whether neighbourhood socioeconomic position (SEP) was associated with neighbourhood public green space availability in a large German city with more than 1 million inhabitants.

Methods: Two different measures were defined for green space availability. Firstly, percentage of green space within neighbourhoods was calculated with the additional consideration of various buffers around the boundaries. Secondly, percentage of green space was calculated based on various radii around the neighbourhood centroid. An index of neighbourhood SEP was calculated with principal component analysis. Log-gamma regression from the group of generalized linear models was applied in order to consider the non-normal distribution of the response variable. All models were adjusted for population density.

Results: Low neighbourhood SEP was associated with decreasing neighbourhood green space availability including 200 m up to 1000 m buffers around the neighbourhood boundaries. Low neighbourhood SEP was also associated with decreasing green space availability based on catchment areas measured from neighbourhood centroids with different radii (1000 m up to 3000 m). With an increasing radius the strength of the associations decreased.

Conclusions: Social unequally distributed green space may amplify environmental health inequalities in an urban context. Thus, the identification of vulnerable neighbourhoods and population groups plays an important role for epidemiological research and healthy city planning. As a methodical aspect, log-gamma regression offers an adequate parametric modelling strategy for positively distributed environmental variables.

© 2017 Elsevier GmbH. All rights reserved.

1. Introduction

The influence of the neighbourhood built environment on urban health and the impact of environmental disparities on health inequalities within cities have become important issues in epidemiological research. There is increasing evidence that built environmental factors are associated with individual health out-

comes and health behaviours, such as physical activity, overweight, or cardiovascular diseases (Feng et al., 2010; Renalds et al., 2010; Schüle and Bolte, 2015; Van Holle et al., 2012).

Both socioeconomic characteristics of individuals or neighbourhoods and built environmental factors play an important role in explaining health inequalities between neighbourhoods. Various conceptual models were developed describing pathways how contextual factors of the neighbourhood environment are linked with individual health behaviours, health outcomes, and well-being of city residents (Diez Roux and Mair, 2010; Gee and Payne-Sturges, 2004; Morello-Frosch and Shenassa, 2006; Schulz and Northridge, 2004). These models share a hypothesis of vulnerability. They suggest that deprived areas or individuals with a low socioeconomic

* Corresponding author at: Institute for Public Health and Nursing Research, Department 5: Social Epidemiology, Grazer Straße 4, 28359 Bremen, Germany.

E-mail addresses: steffen.schuele@uni-bremen.de (S.A. Schüle), katharina.gabriel@uni-bremen.de (K.M.A. Gabriel), gabriele.bolte@uni-bremen.de (G. Bolte).

position (SEP) are exposed to higher environmental burdens and have minor environmental resources available than more affluent neighbourhoods or individuals. Aspects of vulnerability are also captured in conceptual models derived from the environmental justice framework. It is hypothesized that environmental exposures are social unequally distributed (exposure variation by SEP) and that neighbourhoods or individuals with a low SEP are more vulnerable to environmental exposures in terms of effect modification (Bolte et al., 2011).

The concept of 'deprivation amplification' assuming an amplification of individual disadvantage due to environmental burdens has been critically discussed. Evidence suggests that there is no consistent pattern that socioeconomic area deprivation is correlated with a lack of environmental resources which makes further research in this field necessary (Macintyre, 2007).

Epidemiological research often does not refer to a theoretical background on the measurement of neighbourhood SEP. There is a great heterogeneity in neighbourhood studies on how SEP on the neighbourhood level is operationalized. Measures of income, education, and employment on the level of administrative areas are the most often used indicators describing neighbourhood SEP (Leventhal and Brooks-Gunn, 2000; Rajaratnam et al., 2006; Sellström and Bremberg, 2006; van Vuuren et al., 2014).

In terms of environmental resources and their potential health benefits urban green space within cities has received increasing attention in epidemiological, environmental justice, and urban planning research (Corkery, 2015; Jennings et al., 2012; Tzoulas et al., 2007; WHO, 2016; Wolch et al., 2014). There are studies which found out that urban green space is associated with better health and health-promoting behaviours, such as with lower mortality, better perceived general health, better mental health, lower risk of cardiovascular diseases, or increased physical activity (Astell-Burt et al., 2014b; Maas et al., 2009; Mitchell et al., 2011; Mitchell and Popham, 2007; Richardson et al., 2013; van Dillen et al., 2012; Villeneuve et al., 2012). A deeper understanding to what extent green space is distributed by socioeconomic neighbourhood characteristics is a prerequisite to assess whether a socioeconomic unequal distribution of green space enhances environmental health inequalities.

Previous studies in cities in the USA, Canada, New Zealand, Australia, Britain, and Germany showed already that a low neighbourhood SEP is associated with decreasing green space availability (Astell-Burt et al., 2014a; Lakes et al., 2014; Mitchell et al., 2011; Pham et al., 2012; Richardson et al., 2010; Wen et al., 2013). However, there is still need for further studies investigating how neighbourhood SEP is related to green space availability. There is a great heterogeneity across existing studies on how green space availability within and around a neighbourhood is defined and measured. Predominantly, local or national land use data are used to define urban green space mostly in terms of public parks, public urban forests, or other types of vegetated land use types (Astell-Burt et al., 2014b; de Vries et al., 2003; Jones et al., 2009; Mitchell and Popham, 2007, 2008; Wen et al., 2013). Thereby, most studies focus on public green space and do not include domestic gardens. Other studies define urban green space by the use of the normalized difference vegetation index based on remote sensing which does not distinguish between different types of urban green space (Lakes et al., 2014; Villeneuve et al., 2012).

When it comes to the measurement of green space availability on the neighbourhood level, two methods stick out. One the one hand, the percentage of green space in the neighbourhood is calculated based on administrative boundaries, such as census tracts or postal codes (Mitchell et al., 2011; Mitchell and Popham, 2008; Richardson et al., 2010). Thereby, most studies determine the proportion within the neighbourhood itself, however, there are also studies considering a buffer (of e.g. 1000 m) around the neigh-

bourhood additionally (Richardson et al., 2012). On the other hand, there are studies measuring green space availability based on different radii around the neighbourhood centroid (Astell-Burt et al., 2014a; de Vries et al., 2003; Maas et al., 2009). Catchment areas based on different radii around the centroid are not inhibited by administrative neighbourhood boundaries which can vary in their geographic extension and may provide a more precise application of walking distances. There is still a lack of knowledge to what extent such different methods of green space measurement influence relationships between neighbourhood deprivation and green space availability.

Moreover, analysing data of green space availability within and around neighbourhoods as a response variable on a continuous scale with standard linear regression models may be problematic because values can become only zero or positive. Distributions of positive continuous data are often highly skewed and, thus, violate the assumption of a normal distribution. Transforming the response variable or applying nonparametric methods are potential options to overcome this problem, however, they have their drawbacks when it comes to the precision of the estimates and interpretation of results (Feng et al., 2014; Manning and Mullahy, 2001). Previous studies which analysed associations between neighbourhood SEP and urban green space applied bivariate methods, such as analysis of variance (Mitchell et al., 2011) or correlation analysis (Mitchell and Popham, 2008). Others applied ordinary least squares regression in combination with spatial regression models where most of the green space variables were transformed (Shanahan et al., 2014) or negative binomial regression where green space availability was treated as a count variable (Astell-Burt et al., 2014a).

Therefore, this study followed two research questions. Firstly, we investigated whether neighbourhood SEP was associated with neighbourhood green space availability applying generalized linear models with a log-gamma regression in order to consider the non-normal distribution of green space availability as our response variable. Secondly, we analysed whether variations in size and kind of catchment areas of green space availability on the neighbourhood level influenced relationships between neighbourhood SEP and green space.

2. Data and methods

2.1. Neighbourhood delineation

Neighbourhood boundaries of 108 sub districts subdividing 24 main districts were obtained from the city council of Munich, Germany. The 108 sub districts serve for municipal administration and population statistics.

2.2. Green space availability within and around neighbourhoods

Spatial data on various land use types including public green space from 2011 were obtained from the city council of Munich. In our analysis public urban green space included land use types of public parks and public urban forests (deciduous forests, coniferous forests, and mixed forests). Domestic gardens and small green spaces, such as roadside greenery, were not considered.

Five buffers in steps of 200 m (from 200 m up to 1000 m) were generated around each administrative neighbourhood boundary. Firstly, percentages of green space availability were calculated within neighbourhoods only, as most previous studies did. Secondly, neighbourhood green space availability with the additional

consideration of green space within neighbourhood buffers was calculated with the following formula.

$$\text{Green space (GS) (\%)} = \left(\frac{\text{GS in neighbourhood (m}^2\text{)} + \text{GS in buffer (m}^2\text{)}}{\text{neighbourhood size (m}^2\text{)} + \text{GS in buffer (m}^2\text{)}} \right) * 100$$

2.3. Green space availability around neighbourhood centroids

Orientated on radii used in previous studies, five different radii on the range between one and three kilometre (1000 m, 1500 m, 2000 m, 2500 m, and 3000 m) were considered around the neighbourhood centroid. For each catchment area the percentage of available green space was calculated.

Neighbourhood buffers, centroids, and the amount of green space were calculated using ESRI ArcGIS 10.2.2.

2.4. Neighbourhood socioeconomic variables

Eight socioeconomic neighbourhood variables aggregated on the level of 108 administrative neighbourhood districts were considered for index development describing neighbourhood SEP applying principal component analysis (PCA). From the city council of Munich we got data on unemployment (percentage of people in the age group 15–65 years receiving unemployment benefit part II, percentage of unemployed in the age group 15–65 years receiving social security under Hartz IV, percentage of people in the age group below 15 years receiving social assistance), data on foreigners and people with migration history (percentage of residents with no German citizenship, and percentage of residents with a German citizenship and a migration background), and population density (number of inhabitants per km²). Population density was considered as an adjustment variable in multivariate analysis. Data on education and occupation were provided by microm GmbH, Neuss, Germany (percentage of households with lower education, no graduation, and with vocational training). All data were available for the years 2011–2013. From these three years the average value was calculated and used for PCA.

2.5. Statistical analysis

PCA was used as a statistical procedure for generating an index out of the eight correlated variables describing neighbourhood SEP. It is an appropriate method for data reduction of correlated variables and creates new uncorrelated variables, called principal components, which are linear combinations of the initial covariables which explain most of their variance (Tabachnick and Fidell, 2013). The first component had its largest eigenvalue, explained most of the variance, and was therefore used as an indicator for the socioeconomic neighbourhood environment. Higher values of the index imply a lower neighbourhood SEP. Spearman rank correlation coefficients (Spearman's rho) between the single socioeconomic neighbourhood variables and the first component were calculated to check how each neighbourhood socioeconomic indicator was represented in the index. Finally, the index was categorized into quartiles.

We applied log-gamma regression belonging to the group of generalized linear models (GLMs) for analysing associations between neighbourhood SEP and green space availability. GLMs hypothesize that the response variable follows a selected probability distribution of the exponential family. A general link function links the expected mean of the response variable to the linear predictor. In contrast to linear regression where a normal distribution of the response variable is assumed, which is often achieved by transforming the original data, GLMs have the advantage that the link function achieves linearity separately from the distribution of

the response variable. As a result, non-normal response data can be predicted linearly and it is possible to make inferences about arithmetic means while keeping their original scale which makes interpretations of parameter estimates much easier. We chose the gamma distribution as a hypothesized response distribution because it is suitable for modelling positive continuous response variables resulting in left-skewed distributions which is the case for our green space variables (Fox, 2016). The logarithmic function was selected as the link function which assumes a multiplicative effect on the outcome by the selected predictor variables. By exponentiating the coefficients, the linear predictor can be interpreted as the factor by which the arithmetic mean of the outcome is multiplied.

Firstly, our standardized index describing neighbourhood SEP was modelled as a continuous independent variable in multivariate log-gamma regression to analyse linear relationships between neighbourhood SEP and green space availability. Secondly, quartiles of the neighbourhood SEP index were analysed in order to confirm a monotonic trend and to analyse how most deprived neighbourhoods (highest quartile of index) are related to green space availability in comparison to most affluent neighbourhoods (lowest quartile). All models were adjusted for population density and the distribution of the standardized deviance residuals were checked for homoscedasticity.

Log-gamma regression only considers positive values. As a result, areas with zero greenspace are excluded from the analysis. This was mainly the case for our dependent green space variable considering no buffer around the neighbourhood. Therefore, we replaced all 0 values with very small values of 0.1% to consider all neighbourhoods. As a sensitivity analysis we additionally performed log-gamma regression with the original values in order to check whether the estimates differ when neighbourhoods with zero greenspace were excluded.

All statistical analyses were performed using SAS statistical software package version 9.4 (SAS Institute, Cary, NC, USA).

3. Results

3.1. Principal component analysis

The first component from PCA explained 72.5% variance of the eight socioeconomic neighbourhood variables. All socioeconomic neighbourhood variables were adequately represented in the first principal component. Spearman rank correlation coefficients ranged between 0.73 and 0.91 and had *p*-values <0.01 (Table 1).

3.2. Descriptive results

Fig. 1 shows the spatial distribution of neighbourhood SEP across the 108 neighbourhoods in the city of Munich. Neighbourhoods with a low SEP are predominantly located around the city centre in the northern, south-eastern, and south-western part of the city (see Fig. 1).

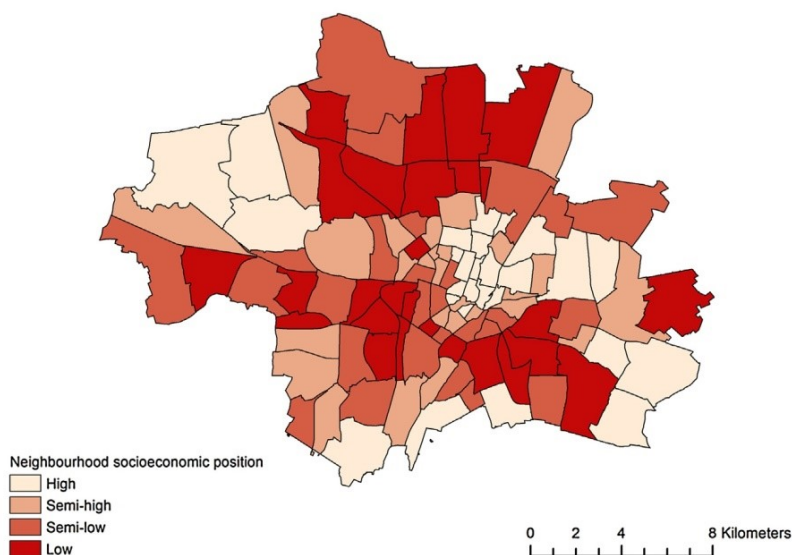
The spatial distribution of public green space is shown in Fig. 2. The largest connected green areas range from the city centre to the north-eastern part. Further large green spaces are found in the western, southern, and south-eastern part of the city along the river Isar (see Fig. 2).

Mean and median percentages of neighbourhood green space availability increased steadily with distance buffers rising from 200 m up to 1000 m (Table 2). There were 22 neighbourhoods with zero green space when no buffer was considered, and three with a 200 m buffer. When a 400 m buffer was taken into account, only one neighbourhood with zero green space was left. Catchment areas of green space availability calculated from neighbourhood centroids

Table 1

Spearman rank correlation coefficients between neighbourhood socioeconomic variables and the first principal component representing neighbourhood SEP.

Neighbourhood socioeconomic variables	Spearman's rho of the first principal component	p-value
Percentage of people in the age group 15–65 years receiving unemployment benefit part II	0.91	<0.01
Percentage of unemployed people in the age group 15–65 years receiving social security under Hartz IV	0.90	<0.01
Percentage of people in the age group below 15 years receiving social assistance	0.91	<0.01
Percentage of residents with no German citizenship	0.73	<0.01
Percentage of residents with a German citizenship and a migration background	0.80	<0.01
Percentage of households with lower education	0.91	<0.01
Percentage of households with no graduation	0.90	<0.01
Percentage of households with vocational training	0.91	<0.01

**Fig. 1.** Spatial distribution of neighbourhood socioeconomic position in 108 neighbourhoods in the city of Munich.

showed a slight increase in median values with an increasing radius from 1000 m up to 3000 m.

3.3. Multivariate associations between neighbourhood SEP and green space availability with different neighbourhood buffers

In multivariate log-gamma regression low neighbourhood socioeconomic position was associated with decreasing neighbourhood green space availability (Table 3). Prevalence ratios for neighbourhood SEP were very similar across all models. For example, with one standard deviation increase of the neighbourhood SEP index on a continuous scale there was on average 21% less green space available within a neighbourhood including a 200 m buffer around the boundaries additionally. When categories of neighbourhood SEP were analysed neighbourhoods with a low SEP had on average 43% less green space available including a 200 m buffer than neighbourhoods with a high SEP.

3.4. Multivariate associations between neighbourhood SEP and green space availability measured from neighbourhood centroids with different radii

A low neighbourhood SEP was also associated with decreasing neighbourhood green space availability based on catchment areas measured from neighbourhood centroids with different radii (Table 4). In both continuous and categorical models low neighbourhood SEP was significantly related with decreasing availability of green space. With an increasing radius there was a slight decrease of the strength of the association. On a continuous scale with one standard deviation increase of the neighbourhood SEP index there

was on average 27% less green space available for the 1000 m radius. For the 3000 m radius with one standard deviation increase of the neighbourhood SEP index there was on average 9% less of green space available. This trend was similar for the categorical models. For the 1000 m radius neighbourhoods with a low SEP had on average 52% less green space available than neighbourhoods with a high neighbourhood SEP whereas for the 3000 m radius low SEP neighbourhoods had on average 21% less green space available than neighbourhoods with a high SEP.

In our sensitivity analysis where neighbourhoods with zero green space were excluded log-gamma regression did not show remarkable differences in the prevalence ratios and 95% confidence intervals. Furthermore, all models showed a reasonable homoscedastic distribution of the standardized deviance residuals (results not shown).

4. Discussion

The first goal of this ecological study was to investigate whether neighbourhood SEP was related to green space availability by applying log-gamma regression. Our analysis showed that a low neighbourhood SEP was significantly associated with lower availability of green space. A second goal of this study was to examine whether different radius-buffering measures to quantify green space availability within and around neighbourhoods influence the parameter estimates. Associations were mostly consistent across models where neighbourhood green space availability was assessed with various radius-buffering methods. There was a trend that with an increasing size of the catchment area of green space availability calculated from neighbourhood centroids the strength



Fig. 2. Spatial distribution of public urban green space in the city of Munich.

Table 2

Description of variables based on different operationalisations of neighbourhood green space availability (N= 108 administrative neighbourhood districts).

Variables	Mean	Median	Std. Dev.	Min	Max	Number of zeros
<i>Green space with neighbourhood buffers</i>						
Green space (no buffer) [%]	9.06	4.69	12.48	0	57.64	22
Green space (200 m buffer) [%]	15.06	10.85	14.27	0	67.13	3
Green space (400 m buffer) [%]	20.60	16.42	15.93	0	74.14	1
Green space (600 m buffer) [%]	26.13	21.86	17.00	0.28	79.38	0
Green space (800 m buffer) [%]	31.65	28.70	17.68	1.05	82.51	0
Green space (1000 m buffer) [%]	37.07	31.91	18.37	4.36	84.56	0
<i>Green space from neighbourhood centroids</i>						
Green space (1000 m radius) [%]	8.77	5.09	9.99	0	42.81	4
Green space (1500 m radius) [%]	9.21	6.20	7.78	0.03	34.38	0
Green space (2000 m radius) [%]	9.21	7.50	5.65	0.17	24.50	0
Green space (2500 m radius) [%]	9.27	8.65	4.39	0.28	22.98	0
Green space (3000 m radius) [%]	9.21	9.02	3.52	0.96	18.74	0
<i>Neighbourhood variables</i>						
Neighbourhood SEP index ^a	0	0	1.00	-1.54	2.35	n.a.
Population density [persons/km ²]	7787.67	5867.25	6060.12	49.49	30209.13	n.a.

Std. Dev. = standard deviation, SEP = socioeconomic position, n.a. = not applicable.

^a Represented by the first standardized principal component.

of the negative association between neighbourhood SEP and green space slightly decreased.

The results of our case study are in line with previous results showing associations between a low neighbourhood SEP and decreasing neighbourhood green space availability. These studies are from cities in Germany, Britain, USA, Canada, New Zealand, and Australia which highlight the international importance of unequal distributions of neighbourhood green space in urban areas (Astell-Burt et al., 2014a; Lakes et al., 2014; Mitchell et al., 2011; Mitchell and Popham, 2008; Pham et al., 2012; Richardson et al., 2010;

Shanahan et al., 2014; Wen et al., 2013). However, there are also studies which found positive association between socioeconomic neighbourhood deprivation and green space availability (Jones et al., 2009; Richardson et al., 2010; Wen et al., 2013).

There is a great heterogeneity across existing studies on how green space availability and neighbourhood SEP was defined and operationalized which may explain mixed results. Most studies used administrative boundaries, predominantly census tracts, as the catchment area for the measurement of green space availability because for such areas aggregated socioeconomic data are available

Table 3

Multivariate associations from log-gamma regression between neighbourhood SEP and neighbourhood green space availability with different neighbourhood buffers (N = 108 administrative neighbourhood districts).

	Green space (no buffer)	Green space (200 m buffer)	Green space (400 m buffer)	Green space (600 m buffer)	Green space (800 m buffer)	Green space (1000 m buffer)
<i>Continuous models</i>						
Intercept (95% CI) [%]	15.58 (10.20–23.78)	19.14 (14.50–25.27)	23.51 (18.68–29.58)	27.60 (22.58–33.73)	30.83 (25.96–36.61)	33.46 (28.82–38.84)
Neighbourhood SEP ^a (PR (95% CI) ^b)	0.84 (0.64–1.08)	0.79 (0.67–0.93)	0.79 (0.69–0.90)	0.80 (0.71–0.89)	0.81 (0.73–0.89)	0.82 (0.75–0.90)
<i>Categorical models</i>						
Intercept (95% CI) [%]	20.47 (10.05–41.66)	23.64 (15.79–35.42)	30.09 (21.96–41.24)	36.47 (27.27–48.78)	39.97 (31.16–51.26)	43.09 (34.67–53.56)
Neighbourhood SEP ^a (PR (95% CI) ^b)						
Low	0.55 (0.25–1.23)	0.57 (0.34–0.95)	0.56 (0.38–0.82)	0.58 (0.41–0.82)	0.60 (0.45–0.80)	0.62 (0.48–0.80)
Semi-low	0.75 (0.34–1.65)	0.76 (0.46–1.25)	0.69 (0.47–1.02)	0.68 (0.48–0.97)	0.70 (0.52–0.94)	0.70 (0.55–0.92)
Semi-high	0.83 (0.36–1.87)	0.98 (0.59–1.64)	0.92 (0.63–1.36)	0.83 (0.59–1.18)	0.84 (0.63–1.13)	0.83 (0.64–1.08)
High	Reference	Reference	Reference	Reference	Reference	Reference

SEP = socioeconomic position; PR = prevalence ratio; CI = confidence interval.

^a standardized with mean = 0 and standard deviation = 1.

^b Prevalence ratios = exponentiated beta estimates from log-gamma regression.

Table 4

Multivariate associations from log-gamma regression between neighbourhood SEP and green space availability measured from neighbourhood centroid with different radii (N = 108 administrative neighbourhood districts).

	Green space (1000 m radius)	Green space (1500 m radius)	Green space (2000 m radius)	Green space (2500 m radius)	Green space (3000 m radius)
<i>Continuous models</i>					
Intercept (95% CI) [%]	12.48 (9.03–17.25)	11.88 (9.36–15.08)	10.18 (8.49–12.20)	9.33 (8.05–10.81)	8.74 (7.73–9.87)
Neighbourhood SEP ^a PR (95% CI) ^b)	0.73 (0.61–0.89)	0.80 (0.70–0.92)	0.85 (0.77–0.94)	0.88 (0.80–0.96)	0.91 (0.84–0.98)
<i>Categorical models</i>					
Intercept (95% CI) [%]	16.90 (11.31–27.39)	15.76 (11.04–22.49)	13.04 (9.96–17.06)	11.46 (9.24–14.22)	10.26 (8.60–12.23)
Neighbourhood SEP ^a (PR (95% CI) ^b)					
Low	0.48 (0.27–0.84)	0.58 (0.39–0.88)	0.65 (0.48–0.90)	0.71 (0.55–0.92)	0.79 (0.64–0.97)
Semi-low	0.60 (0.34–1.07)	0.66 (0.44–1.00)	0.69 (0.50–0.95)	0.73 (0.57–0.95)	0.77 (0.62–0.95)
Semi-high	0.96 (0.54–1.70)	0.83 (0.55–1.26)	0.81 (0.60–1.12)	0.83 (0.64–1.07)	0.79 (0.64–0.97)
High	Reference	Reference	Reference	Reference	Reference

SEP = socioeconomic position; PR = prevalence ratio; CI = confidence interval.

^a standardized with mean = 0 and standard deviation = 1.

^b Prevalence ratios = exponentiated beta estimates from log-gamma regression.

(Lakes et al., 2014; Mitchell et al., 2011; Mitchell and Popham, 2008; Richardson et al., 2010; Wen et al., 2013). However, there are also studies mainly from urban planning research which apply interpolation and weighting techniques to disaggregate socioeconomic data on the area level to smaller units in order to combine them with green space measures on a smaller scale (Pham et al., 2012; Shanahan et al., 2014).

In our analysis definition of public green space included parks and urban forests derived from local land use data from the city of Munich. Although definitions of green space are partial different across studies, there is a noticeable trend that a negative relation between low neighbourhood SEP and neighbourhood green space availability is most consistent for studies which assessed general green space by summarizing various forms of urban green, such as parks, trees, shrubs, lawn, forests, or vegetation indices derived from remote sensing data (Astell-Burt et al., 2014a; Lakes et al., 2014; Mitchell et al., 2011; Mitchell and Popham, 2008; Richardson et al., 2010; Wen et al., 2013). When specific types of public green are analysed in relation to neighbourhood SEP, such as parks or usable green space, opposing associations were also found in previous studies (Jones et al., 2009; Richardson et al., 2010; Wen et al., 2013). Moreover, some of these studies applied distance based methods to measure access to green space areas which might also explain different results (Jones et al., 2009; Wen et al., 2013). Wen et al. found that more deprived neighbourhoods across urban areas in the USA have less availability of vegetated land, but have

shorter distances to public parks (Wen et al., 2013). A study by Richardson et al. identified that in urban New Zealand disadvantaged neighbourhoods have less general green space, however, have marginally more usable green space available than more affluent neighbourhoods (Richardson et al., 2010). Results from a study in the city of Bristol showed that more deprived neighbourhoods have lower mean distances to public green spaces. Exceptions were well-maintained formal green spaces with structured paths and an organised outline, and sport green spaces for which distances were higher in deprived areas (Jones et al., 2009). Such results indicate that the distribution of different types of green space in urban areas play a considerable role in the assessment of socioeconomic driven environmental inequalities within cities. When specific health outcomes and behaviours and their relations with urban green are analysed various types and quality indicators of green space are of great interest. Public parks and other recreational facilities could be more relevant in the context of physical activity (Bancroft et al., 2015; Kaczynski and Henderson, 2007) whereas overall green space or urban forests could be more important in relation to the reduction of air pollution and temperature regulation which support healthy living environments (Bowler et al., 2010; Nowak et al., 2006). Furthermore, one recent study found out that general green space availability, measured with the normalized difference vegetation index, around the home address of study participants has a positive impact on depressive symptoms (Cohen-Cline et al., 2015).

Our analysis follows the rationale that urban green space serves as an environmental resource and that a socioeconomic unequal distribution of such a resource may amplify health inequalities. It should be noted that a distinction of neighbourhood environments into 'goods' and 'bads' may be too simplistic (Macintyre, 2007). Besides the salutogenic evidence for urban green there are also studies analysing potential pathogenic effects of green space, such as higher risks of asthma and allergies (Dadvand et al., 2014; Fuertes et al., 2016). However, there is still no clear evidence and studies showed mixed findings.

Besides that, it is important to mention that personal attributes may modify relations between green space and health. Aspects of gender play a significant role when interconnections between green space and health are assessed. Perceptions and uses of natural environments are influenced by aspects of gender, and scientific evidence suggests that women are more vulnerable to environmental degradation, such as fear of crime (Sreetheran and van den Bosch, 2014), which may attenuate salutogenic effects of green space for women (MacBride-Stewart et al., 2016).

There is evidence that different geographic scales in environmental justice related studies can influence results on associations between socioeconomic indicators and environmental burdens or resources (Baden et al., 2007). Our study showed that both radius-buffering methods for defining the catchment area of neighbourhood green space, one based on administrative boundaries and one based on centroids, revealed significant negative associations between low neighbourhood SEP and green space availability. There were differences in the strengths of the associations especially for catchment areas based on neighbourhood centroids. With increasing radii the strength of the associations decreased. For catchment areas based on administrative neighbourhood boundaries and relating buffers parameter estimates were more homogeneous across models. Our analysis indicates that small administrative units within cities provide a good basis for the analysis of socioeconomically driven environmental inequalities within cities in an ecological analysis. However, our results also suggest that it is recommendable to compare different catchment areas for green space availability on the neighbourhood level. Future studies which analyse associations between green space and health or health related behaviours stratified by further socio-demographic characteristics, such as different age groups or gender, should consider different catchment areas in order to consider different walking capabilities of different population groups (Yang and Diez-Roux, 2012).

There are some limitations in our study which need to be mentioned. Our study focused on overall public green space availability and did not consider private green space. Furthermore, we had no data on quality characteristics of green space areas which can also vary by socioeconomic neighbourhood characteristics and influence usage of green space areas (Jones et al., 2009; Moore et al., 2008; Weiss et al., 2011). The catchment area definitions based on administrative neighbourhood boundaries were used as a proxy for the close living environment and available green space in walking distance. However, it was not possible to calculate distances to green spaces from individual home addresses of neighbourhood residents.

One of the main strengths of our study is that we considered various catchment areas for green space availability representing the close walkable neighbourhood environment in order to check whether different area definitions influence our hypotheses that more deprived neighbourhoods have less green space available. Moreover, we applied log-gamma regression from the group of GLMs as a powerful parametric approach which adequately addressed the distribution of our response variable. Furthermore,

we combined various socioeconomic variables to one index applying PCA in order to adequately represent neighbourhood SEP.

5. Conclusions

Our study in a large German city showed that neighbourhoods with a lower SEP have less accessible public green space within their boundaries and in their close surroundings than more affluent neighbourhoods. Against the background of potential health effects of public green space, a socioeconomic unequal distribution of green space may therefore amplify health inequalities within cities. Furthermore, the analysis of socioeconomic related green space variations on the neighbourhood level should include different sizes of catchment areas through the additional consideration of neighbourhood buffers or different radii around the centroid because they can influence the estimates. From a methodological point of view log-gamma regression from the group of GLMs offers a suitable parametric modelling approach for positively distributed environmental variables.

Conflict of interest

The authors declare no conflict of interest.

Financial disclosure

S.A. Schüle received a doctoral scholarship within the framework of the Junior Research Group Salus, which was funded by the foundation 'Fritz und Hildegard Berg Stiftung' within the 'Stifterverband für die Deutsche Wissenschaft e.V.', Essen, Germany. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Acknowledgements

The authors thank Werner Brannath for statistical consulting (Competence Centre for Clinical Trials, University of Bremen), Birgit Reineke for data management, the Department of Statistic in the city of Munich (Ronald Bauch), the Department of Health and Environment in the city of Munich (Uta Zimmermann, Gabriele Spies), the Department of City Planning and Building Regulations in the city of Munich (Andreas Peter, Kurt Damaschke), and the Jufo-Salus (Junior Research Group 'The city as a healthy living environment independent of social inequalities').

References

- Astell-Burt, T., Feng, X.Q., Mavoa, S., Badland, H.M., Giles-Corti, B., 2014a. Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health* 14.
- Astell-Burt, T., Mitchell, R., Hartig, T., 2014b. The association between green space and mental health varies across the lifecourse: a longitudinal study. *J. Epidemiol. Commun. Health* 68, 578–583.
- Baden, B.M., Noonan, D.S., Turaga, R.M.R., 2007. Scales of justice: is there a geographic bias in environmental equity analysis? *J. Environ. Plann. Man.* 50, 163–185.
- Bancroft, C., Joshi, S., Rundle, A., Hutson, M., Chong, C., Weiss, C.C., Genkinger, J., Neckerman, K., Lovasi, G., 2015. Association of proximity and density of parks and objectively measured physical activity in the United States. *Syst. Rev. Soc. Sci. Med.* 138, 22–30.
- Bolte, G., Pauli, A., Hornberg, C., 2011. Environmental justice: social disparities in environmental exposures and health: overview. In: Jerome, O.N. (Ed.), *Encyclopedia of Environmental Health*. Elsevier, Burlington, pp. 459–470.
- Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S., 2010. Urban greening to cool towns and cities: a systematic review of the empirical evidence. *Landscape Urban. Plan.* 97, 147–155.
- Cohen-Cline, H., Turkheimer, E., Duncan, G.E., 2015. Access to green space, physical activity and mental health: a twin study. *J. Epidemiol. Commun. Health* 69, 523–529.
- Corkery, L., 2015. Beyond the park: linking urban greenspaces, human well-being and environmental health. In: Barton, H., Thompson, S., Grant, M., Burgess, S.

- (Eds.), *The Routledge Handbook of Planning for Health and Well-being: Shaping a Sustainable and Healthy Future*. Routledge, pp. 239–253.
- Dadvand, P., Villanueva, C.M., Font-Ribera, L., Martinez, D., Basagana, X., Belmonte, J., Vrijheid, M., Grazuleviciene, R., Kogevinas, M., Nieuwenhuijsen, M.J., 2014. Risks and benefits of green spaces for children: a cross-sectional study of associations with sedentary behavior, obesity, asthma, and allergy. *Environ. Health Perspect.* 122, 1329–1335.
- de Vries, S., Verheij, R.A., Groenewegen, P.P., Spreeuwenberg, P., 2003. Natural environments – healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environ. Plann. A* 35, 1717–1731.
- Diez Roux, A.V., Mair, C., 2010. Neighborhoods and health. *Ann. N. Y. Acad. Sci.* 1186, 125–145.
- Feng, J., Glass, T.A., Curriero, F.C., Stewart, W.F., Schwartz, B.S., 2010. The built environment and obesity: a systematic review of the epidemiologic evidence. *Health Place* 16, 175–190.
- Feng, C., Wang, H., Lu, N., Chen, T., He, H., Lu, Y., Tu, X.M., 2014. Log-transformation and its implications for data analysis. *Shanghai Arch. Psychiatry* 26, 105–109.
- Fox, J., 2016. *Applied Regression Analysis and Generalized Linear Models*, 3rd ed. SAGE, Los Angeles.
- Fuertes, E., Markevych, I., Bowatte, G., Gruzjeva, O., Gehring, U., Becker, A., Berdel, D., von Berg, A., Bergstrom, A., Brauer, M., Brunekreef, B., Bruske, I., Carlsten, C., Chan-Yeung, M., Dharmage, S.C., Hoffmann, B., Klumpp, C., Koppelman, G.H., Kozryskij, A., Korek, M., Kull, I., Lodge, C., Lowe, A., MacIntyre, E., Pershagen, G., Standl, M., Sugiri, D., Wijga, A., MACS, Heinrich, J., 2016. Residential greenness is differentially associated with childhood allergic rhinitis and aeroallergen sensitization in seven birth cohorts. *Allergy* 71, 1461–1471.
- Gee, G.C., Payne-Sturges, D.C., 2004. Environmental health disparities: a framework integrating psychosocial and environmental concepts. *Environ. Health Perspect.* 112, 1645–1653.
- Jennings, V., Gaiher, C.J., Schulerbrandt Gragg, R., 2012. Promoting environmental justice through urban green space access: a synopsis. *Environ. Justice* 5, 1–7.
- Jones, A., Hillsdon, M., Coombes, E., 2009. Greenspace access, use, and physical activity: understanding the effects of area deprivation. *Prev. Med.* 49, 500–505.
- Kaczynski, A.T., Henderson, K.A., 2007. Environmental correlates of physical activity: a review of evidence about parks and recreation. *Leisure Sci.* 29, 315–354.
- Lakes, T., Bruckner, M., Kramer, A., 2014. Development of an environmental justice index to determine socio-economic disparities of noise pollution and green space in residential areas in Berlin. *J. Environ. Plann. Man.* 57, 538–556.
- Leventhal, T., Brooks-Gunn, J., 2000. The neighborhoods they live in: the effects of neighborhood residence on child and adolescent outcomes. *Psychol. Bull.* 126, 309–337.
- Maas, J., Verheij, R.A., de Vries, S., Spreeuwenberg, P., Schellevis, F.G., Groenewegen, P.P., 2009. Morbidity is related to a green living environment. *J. Epidemiol. Commun. Health* 63, 967–973.
- MacBride-Stewart, S., Gong, Y., Antell, J., 2016. Exploring the interconnections between gender, health and nature. *Public Health* 141, 279–286.
- Macintyre, S., 2007. Deprivation amplification revisited; or, is it always true that poorer places have poorer access to resources for healthy diets and physical activity? *Int. J. Behav. Nutr. Phys. Act.* 4, 32.
- Manning, W.G., Mullahy, J., 2001. Estimating log models: to transform or not to transform? *J. Health Econ.* 20, 461–494.
- Mitchell, R., Popham, F., 2007. Greenspace, urbanity and health: relationships in England. *J. Epidemiol. Commun. Health* 61, 681–683.
- Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet* 372, 1655–1660.
- Mitchell, R., Astell-Burt, T., Richardson, E.A., 2011. A comparison of green space indicators for epidemiological research. *J. Epidemiol. Commun. Health* 65, 853–858.
- Moore, L.V., Diez Roux, A.V., Evenson, K.R., McGinn, A.P., Brines, S.J., 2008. Availability of recreational resources in minority and low socioeconomic status areas. *Am. J. Prev. Med.* 34, 16–22.
- Morello-Frosch, R., Shenassa, E.D., 2006. The environmental Riskscape and social inequality: implications for explaining maternal and child health disparities. *Environ. Health Perspect.* 114, 1150–1153.
- Nowak, D.J., Crane, D.E., Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Gree.* 4, 115–123.
- Pham, T.T.H., Apparicio, P., Seguin, A.M., Landry, S., Gagnon, M., 2012. Spatial distribution of vegetation in Montreal: an uneven distribution or environmental inequity? *Landscape Urban. Plan* 107, 214–224.
- Rajaratnam, J.K., Burke, J.G., O'Campo, P., 2006. Maternal and child health and neighborhood context: the selection and construction of area-level variables. *Health Place* 12, 547–556.
- Renalds, A., Smith, T.H., Hale, P.J., 2010. A systematic review of built environment and health. *Fam. Commun. Health* 33, 68–78.
- Richardson, E., Pearce, J., Mitchell, R., Day, P., Kingham, S., 2010. The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility. *BMC Public Health* 10.
- Richardson, E.A., Mitchell, R., Hartig, T., de Vries, S., Astell-Burt, T., Frumkin, H., 2012. Green cities and health: a question of scale? *J. Epidemiol. Commun. Health* 66, 160–165.
- Richardson, E.A., Pearce, J., Mitchell, R., Kingham, S., 2013. Role of physical activity in the relationship between urban green space and health. *Public Health* 127, 318–324.
- Schüle, S.A., Bolte, G., 2015. Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: a systematic review of multilevel studies. *PLoS One* 10, e0123456.
- Schulz, A., Northridge, M.E., 2004. Social determinants of health: implications for environmental health promotion. *Health Educ. Behav.* 31, 455–471.
- Sellström, E., Bremberg, S., 2006. The significance of neighbourhood context to child and adolescent health and well-being: a systematic review of multilevel studies. *Scand. J. Public Health* 34, 544–554.
- Shanahan, D.F., Lin, B.B., Gaston, K.J., Bush, R., Fuller, R.A., 2014. Socio-economic inequalities in access to nature on public and private lands: A case study from Brisbane, Australia. *Landscape Urban. Plan.* 130, 14–23.
- Sreetheran, M., van den Bosch, C.C.K., 2014. A socio-ecological exploration of fear of crime in urban green spaces – a systematic review. *Urban For. Urban Gree.* 13, 1–18.
- Tabachnick, B.G., Fidell, L.S., 2013. *Using Multivariate Statistics*, 6th ed. Pearson Education, Boston.
- Tzoulas, K., Korpela, K., Venn, S., Yi-Pelkonen, V., Kazmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. *Landscape Urban. Plan.* 81, 167–178.
- van Dillen, S.M., de Vries, S., Groenewegen, P.P., Spreeuwenberg, P., 2012. Greenspace in urban neighbourhoods and residents' health: adding quality to quantity. *J. Epidemiol. Commun. Health* 66, e8.
- Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., De Bourdeaudhuij, I., 2012. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health* 12, 807.
- van Vuuren, C.L., Reijneveld, S.A., van der Wal, M.F., Verhoeff, A.P., 2014. Neighborhood socioeconomic deprivation characteristics in child (0–18 years) health studies: a review. *Health Place* 29, 34–42.
- Villeneuve, P.J., Jerrett, M., Su, J.G., Burnett, R.T., Chen, H., Wheeler, A.J., Goldberg, M.S., 2012. A cohort study relating urban green space with mortality in Ontario, Canada. *Environ. Res.* 115, 51–58.
- WHO, 2016. *Urban Green Spaces and Health*. WHO Regional Office for Europe, Copenhagen.
- Weiss, C.C., Purciel, M., Bader, M., Quinn, J.W., Lovasi, G., Neckerman, K.M., Rundle, A.G., 2011. Reconsidering access: park facilities and neighborhood disamenities in New York City. *J. Urban Health* 88, 297–310.
- Wen, M., Zhang, X.Y., Harris, C.D., Holt, J.B., Croft, J.B., 2013. Spatial disparities in the distribution of parks and green spaces in the USA. *Ann. Behav. Med.* 45, S18–S27.
- Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban green space, public health, and environmental justice: the challenge of making cities 'just green enough'. *Landscape Urban. Plan.* 125, 234–244.
- Yang, Y., Diez-Roux, A.V., 2012. Walking distance by trip purpose and population subgroups. *Am. J. Prev. Med.* 43, 11–19.

Annex A.5 Mapping environmental inequalities relevant for health for informing urban planning interventions-a Case Study in the city of Dortmund, Germany.

Reference:

Flacke, J., Schüle, S. A., Köckler, H., & Bolte, G. (2016). Mapping environmental inequalities relevant for health for informing urban planning interventions-a case study in the city of Dortmund, Germany. *International Journal of Environmental Research and Public Health*, 13(7). doi: 10.3390/ijerph13070711

Link to full article:

<http://www.mdpi.com/1660-4601/13/7/711>



Article

Mapping Environmental Inequalities Relevant for Health for Informing Urban Planning Interventions—A Case Study in the City of Dortmund, Germany

Johannes Flacke ^{1,*}, Steffen Andreas Schüle ², Heike Köckler ³ and Gabriele Bolte ²

¹ Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, P.O. Box 6, Enschede 7500 AE, The Netherlands

² Department of Social Epidemiology, Institute for Public Health and Nursing Research, University of Bremen, Grazer Str. 4, Bremen 28359, Germany; steffen.schuele@uni-bremen.de (S.A.S.); gabriele.bolte@uni-bremen.de (G.B.)

³ Department of Community Health, Hochschule für Gesundheit, Gesundheitscampus 6–8, Bochum 44801, Germany; heike.koeckler@hs-gesundheit.de

* Correspondence: j.flacke@utwente.nl; Tel.: +31-53-4874-381

Academic Editor: Nelson Gouveia

Received: 24 April 2016; Accepted: 8 July 2016; Published: 13 July 2016

Abstract: Spatial differences in urban environmental conditions contribute to health inequalities within cities. The purpose of the paper is to map environmental inequalities relevant for health in the City of Dortmund, Germany, in order to identify needs for planning interventions. We develop suitable indicators for mapping socioeconomically-driven environmental inequalities at the neighborhood level based on published scientific evidence and inputs from local stakeholders. Relationships between socioeconomic and environmental indicators at the level of 170 neighborhoods were analyzed continuously with Spearman rank correlation coefficients and categorically applying chi-squared tests. Reclassified socioeconomic and environmental indicators were then mapped at the neighborhood level in order to determine multiple environmental burdens and hotspots of environmental inequalities related to health. Results show that the majority of environmental indicators correlate significantly, leading to multiple environmental burdens in specific neighborhoods. Some of these neighborhoods also have significantly larger proportions of inhabitants of a lower socioeconomic position indicating hotspots of environmental inequalities. Suitable planning interventions mainly comprise transport planning and green space management. In the conclusions, we discuss how the analysis can be used to improve state of the art planning instruments, such as clean air action planning or noise reduction planning towards the consideration of the vulnerability of the population.

Keywords: environmental inequalities; health determinants; health equity indicators; urban planning; neighborhood; environmental justice; health inequalities; built environment; socioeconomic position

1. Introduction

The World Health Organization (WHO) and UN Habitat (United Nations Human Settlements Programme) acknowledge in their 2010 report *The Hidden Cities* that “Where in a city you live and how the city is governed can determine whether or not one benefits from city living” [1]. Such spatial differences in urban areas resulting from environmental conditions in which people grow, live, work and age contribute to health inequalities within cities [2].

In the literature, two explanations for spatial health inequalities are discussed. First, at the level of aggregated data, health differences between populations of different areas can be attributed to

differences in the composition of neighborhood residents relating to individual socioeconomic status or health-related behaviors (compositional effect). Second, spatial variations in health outcomes are attributed to the characteristics of the local built and social environment (contextual effect) [3–7]. Relevant characteristics of the built environment comprise both environmental burdens, e.g., air quality and noise, and environmental benefits, e.g., access to parks and services. There is evidence that both aggregated socioeconomic characteristics of neighborhoods and built environmental factors have an independent effect on individual health outcomes [8–13].

Conceptual models that describe social inequalities in health outcomes [14] are descriptive and useful for identifying determinants affecting the health of individuals. If these models also include factors describing the built environment, they can be used to ascertain whether specific groups of society are facing a disproportionate share of environmental burdens compared to other groups. “The term ‘disproportionate’ means that the magnitude of health and environmental impacts is greater for a given community or population as compared to a reference counterpart, such as a comparable community or the area surrounding the target community” [15] (p. 171f). The notion of disproportionate share of burdens is also applied regularly in environmental justice analyses [16,17]. According to Walker [18] (p. 40f), an environmental justice analysis is based on the concepts of inequality as a descriptive term and justice as a normative term. In this paper, we focus solely on the (descriptive) identification of environmental inequalities relevant for health.

Addressing environmental health inequalities has become an important issue in recent years, particularly in policies relating to urban development and environmental planning, because suitable planning interventions can affect health through impacts on the context in which individuals live [19,20]. Gelormino et al. [21] identified the built environment as an important policy domain having an impact on health inequalities, although it is rather seldom addressed. Local plans and programs, such as air quality plans, noise protection measures and the development of urban green infrastructure, are typical examples of suitable planning-related interventions. Bambra et al. [22] found evidence that urban planning interventions, particularly in the housing and transport sectors, e.g., traffic calming schemes, promotion of walking and cycling and changes in housing infrastructure, may diminish social gradients in health. Accordingly, Braubach and Grant [23] call for an integrated approach involving urban planners, public and environmental health professionals, other relevant sectors and administrations at different levels in order to improve physical, mental and social well-being by means of urban planning.

Recent international programs and projects, such as the current phase of the WHO Healthy Urban Planning Initiative [20] and the Healthy Urban Development Checklist [24], have picked up these issues striving for a better integration of planning and health in order to mitigate health inequalities. However, in practice, Abernethy [25] observes “siloes problem solving attempts” limiting a successful collaboration between various groups in order to solve environmental health-related problems. De Leeuw et al. [26] report barriers to integrating health plans with land use or other local governmental plans, including lack of collaboration across sectors, workforce capacity issues and the complexity of council planning requirements. Other factors limiting the collaboration between public health and urban planning, as observed in this project, are of a terminological, as well as a methodological nature. For instance, the population-based approach of public health studies, sometimes neglecting contextual, location-related impacts, contrasts with the spatial, location-based approach of urban planning.

A promising approach to addressing urban health inequalities is the development and application of urban health equity indicators. Friel et al. [27] (p. 870) claim that a comprehensive range of indicators is needed to address social and environmental determinants of health equity. In its 1999 report on environmental health indicators [28], the WHO demanded the development of such indicators in order to support and monitor policies on environment and health at all levels, though at that time, it did not explicitly mention health inequalities. Two subsequent WHO reports [2,29] explicitly postulate the development of health equity indicators, particularly for urban areas in the Global South,

to monitor social determinants of health and to develop suitable interventions. Fairburn and Smith [30] developed an indicator-based approach including health inequalities from an integrated perspective of environmental justice and quality of life for the region of South Yorkshire. The need for information on health disparities for small geographic areas is stressed by Rothenberg et al. [31], who developed an urban health index for census tracts for the City of Atlanta, U.S., based on indicators for seven health determinants. Corburn and Cohen [1] discuss how the development of such indicators can act as an instrument for urban health governance, as it helps to identify relevant health policy issues, to generate standards for health equity issues and to improve public accountability and transparency. In addition to their function of assessing and monitoring health inequalities, such urban health equity indicators may also be used to support local stakeholders in identifying planning interventions addressing health inequalities [32].

This paper aims to identify socioeconomically-driven environmental inequalities relevant for health in order to determine the available options for planning interventions from a city-wide perspective by means of neighborhood indicators. To illustrate the applicability of the approach, we calculated all neighborhood indicators for the city of Dortmund, Germany, as the case study area, representing typical medium- to large-sized cities facing significant differences in living and environmental quality, as well as socio-structural composition. Building upon the Spatial Urban Health Equity Indicators (SUHEI) framework [33], we first developed suitable indicators, reflecting problematic environmental health-related conditions in Dortmund. We then applied statistical correlation analysis in order to determine associations between socioeconomic indicators and environmental burdens and resources at the neighborhood level in order to identify health-related inequalities between 170 neighborhoods of Dortmund. The results could assist with the targeting of appropriate planning-related interventions. Our hypothesis is that in Dortmund, people living in neighborhoods with a low socioeconomic position are disproportionately more exposed to negative environmental conditions affecting their health than people living in neighborhoods with a higher socioeconomic position.

2. Materials and Methods

The Spatial Urban Health Equity Indicators (SUHEI) framework [33] allows us to map exposure to environmental factors affecting health determined by various drivers and pressures. The purpose of the model is to map areas showing a disproportionate exposure of certain socioeconomic groups to environmental burdens in order to identify appropriate planning interventions. Building upon the ideas of Morris et al. [34], who added social context variables to the Driving force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework [28] characterizing the population, the SUHEI framework combines elements of environmental health-related cause-effect indicator frameworks [35] with common (environmental) health equity models [14].

The SUHEI framework distinguishes driver, state and exposure indicators of determinants of health, captured on multiple spatial scales (Figure 1). Drivers, appearing on various scales from national to sub-local, represent factors that motivate and push the environmental or social processes involved, such as increasing traffic density, public spending or urban development. State indicators, reflecting the current status, map concrete environmental stressors and resources (burdens and benefits), as well as relevant social context variables, both at the city and neighborhood level. Finally, exposure indicators relate the environmental state to social context indicators in order to spatially target health inequalities, e.g., neighborhoods where a high level of noise-related impacts matches with a disproportionately higher share of unemployed or deprived inhabitants. By combining multiple environmental burdens and benefits, cumulative environmental impacts may also be related to social context factors [36]. Exposure indicators, mapped at the neighborhood level, are intended to guide planners in identifying hotspots where specific action needs to be taken, while state and driver indicators help to define what kind of measures are to be taken.

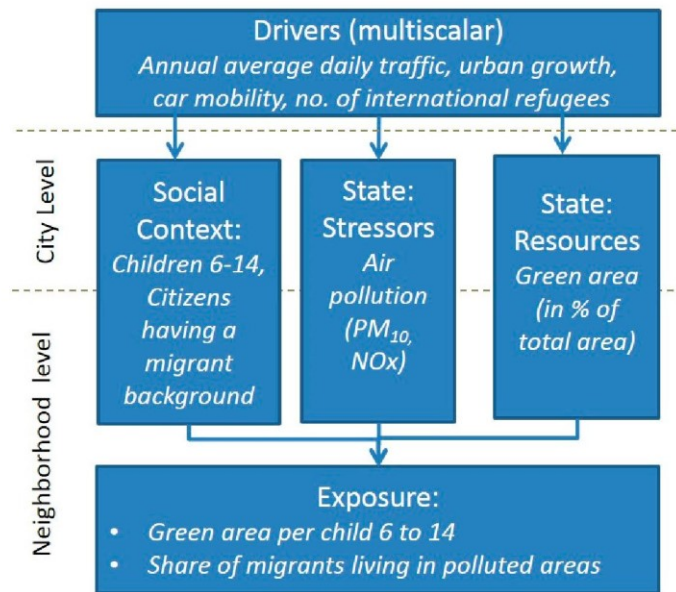


Figure 1. Spatial Urban Health Equity Indicator Framework (SUHEI) (after [33]).

The purpose of the indicator model is to examine geographic patterns and identify hotspots of environmental socioeconomically-driven health inequalities. Therefore, state, social context and exposure indicators included in the model are measured in a spatially-explicit manner on a neighborhood scale. In this context, neighborhoods are understood as determining the availability of and access to health-relevant resources in a geographically-defined area [3]. The mapping of indicators at the neighborhood level is indispensable for two reasons. Firstly, neighborhoods are a typical size for health-related urban planning interventions. Secondly, taking into account that environmental justice issues are very sensitive to scale [37], neighborhoods are sufficiently small in size and homogeneous in terms of their socio-spatial structure to allow us to derive evidence of disproportionate impacts.

The city of Dortmund is divided into 170 neighborhoods ranging from 0.1 km² to 6.2 km² in size. These neighborhoods can be distinguished into urban and suburban neighborhoods, based on a number of socio-demographic, economic, mobility and housing variables. A cluster analysis carried out by the city administration [38] distinguishes 3 different types of urban clusters containing in total 80 neighborhoods (two clusters of around 150 inhabitants/ha population density, one cluster showing a population density of 350 inhabitants/ha) and 2 types of suburban clusters with a total of 90 neighborhoods both having a population density of about 80–90 inhabitants per ha.

2.1. Case Study Area

The city of Dortmund (280 km²) is located in the western part of Germany in the former coal mining and steel-producing, highly urbanized region of the Ruhr. The city is home to nearly 600,000 inhabitants [39]. As a result of the economic boost in the middle of the 20th century, Dortmund attracted a large number of migrant workers. Since the 1980s, Dortmund has been through and continues to go through a long-lasting economic transformation due to the closure of coal mines and steel production companies, resulting in a high unemployment rate (12.5%, in Germany 6.7% (2014)) [39,40]. This ongoing transformation process towards a business, trade and service-oriented local economy has resulted in a highly fragmented city revealing large socio-economic disparities.

The city is an archetypical example of many medium- to large-sized cities in Germany facing significant differences in living and environmental quality, as well as the socio-structural composition of its population after going through a long-lasting phase of socio-economic change. The outcomes of this process are urban land use patterns exhibiting a close proximity of residential, industrial and

commercial structures, which may eventually bring benefits of increasing vitality and livability of the neighborhood, but are on the other hand typically associated with negative environmental impacts [41]. Dortmund is characterized by strong social and ethnic segregation [42]. The city's divide into rather disadvantaged neighborhoods in the north and better off neighborhoods in the south is typical for the entire Ruhr region. Finally, Dortmund reveals significant differences in health outcomes. The average age at death in the districts of Dortmund in 2011 ranges from 66.3 years in the Nordstadt district to 76.3 years in the Hombruch district [43].

2.2. Dataset and Methods

In order to obtain an accurate comparison between neighborhoods, all indicators used in this study are mapped as proportions. Environmental state indicators are measured as impacted area as a percentage of the total neighborhood area, while social context indicators are calculated as the number of people showing certain attributes as a percentage of the total population in the neighborhood (Supplementary Materials, Table S1). Taking the entire area of the neighborhood into account acknowledges the fact that the inhabitants also make use of the non-built-up areas, such as parks, roads, public spaces, e.g., for walking, recreation and working, and they are also exposed to environmental burdens in these areas. The focus on neighborhoods as spatial units of the analysis accords with the availability of socio-economic data acknowledging that this is not necessarily equal to the area of environmental impacts. In order to indicate the need for intervention, environmental indicators are calculated as the proportion of areas where the level of detrimental environmental factors exceeds defined threshold values. The study makes use of the datasets as given in Tables 1 and 2 to calculate the selected indicators. The GIS and census data used are provided, unless otherwise noted, by the City of Dortmund. All census data of socio-economic variables are measured at the neighborhood level. All indicators are calculated using ArcGIS 10.3 (Redlands, CA, USA).

Table 1. GIS datasets.

Data Set	Year	Details
Noise impact areas: noise levels measured as annual average of 24 h noise emissions, in L_{den} db(A)	2013	Noise pollution data are modelled for five sources of noise emissions (train, tram, cars, industry, airport), using a noise dispersion model [44]
Ambient air quality: PM_{10} and NO_2 measured as annual average emissions, in $\mu g/m^3$	Data from 2008 to 2012, modeled in 2013	Emissions from various sources (transport, industry, housing) modelled in a 125×125 -m grid system using the dispersion model [45]
Land use ¹ : current land use, mapped in 150 categories	2014	Mapped from aerial photographs at the 1:5000 scale

¹ Data provided by Regionalverband Ruhr (RVR) [46].

Table 2. Census datasets.

Data Set	Year	Details
Total population	2013	Total number of inhabitants per neighborhood
Working population	2013	Total number of inhabitants per neighborhood between 15 and 65 (working age)
Unemployed population	2013	Total number of inhabitants per neighborhood receiving unemployment benefit subsistence (SGBII)
Population having a background of migration	2013	Total number of inhabitants per neighborhood having a background of migration (either themselves or at least one of their parents not being German)
Population receiving welfare aids	2014	Total number of inhabitants of non-working age per neighborhood receiving subsistence (welfare aids)

Spearman rank correlation coefficients between socioeconomic neighborhood variables were calculated in order to identify a representative indicator describing neighborhood socioeconomic position. Relationships between neighborhood socioeconomic position and environmental variables were analyzed on a continuous scale with Spearman rank correlation coefficients. Finally, quartiles of neighborhood socioeconomic variables and environmental variables were generated (Supplementary Materials, Table S2). Relationships between categorical socioeconomic and environmental variables were analyzed with chi-squared tests. All statistical analyses were performed using SAS statistical software package Version 9.4 (SAS Institute, Cary, NC, USA). In order to map cumulative environmental burdens, categorical environmental variables categorized in quartiles from 1 (low) to 4 (very high) were added. In doing so, all indicators were weighted equally. The indicator green areas indicating an environmental benefit were added in reverse order.

2.3. Indicator Development

The selection of indicators for mapping socioeconomically-driven environmental health inequalities in Dortmund was problem-driven and context-specific following a deductive indicator development approach [47]. The selection was guided by recent environmental health studies, theories and conceptual models, as well as the input of stakeholders from the case study area. Selection criteria were the indicators' relevance for environmental health inequalities, their recognition as a health problem by local stakeholders and the possibility of their being influenced by urban planning.

The WHO [48] names physical activity, social impacts, air pollution, noise exposure and unintentional injuries as the main determinants of health in urban settings. From these, the authors identify physical activity, air pollution and noise impacts as the main aspects that may be influenced by urban planning. Studies analyzing socioeconomically-driven environmental health inequalities in Germany based on aggregated data often use similar datasets and indicators, partly because they offer an accurate reflection of the particular problems of many German cities, partly because the datasets are often available for municipalities. Lakes et al. [49] used transport-induced noise data for measuring environmental burdens and a vegetation index as an indicator for environmental benefits in Berlin. As social context factors, the same authors used a highly aggregated index, including factors, such as unemployment, social welfare recipients, child poverty and inhabitants under the age of 18 with an immigrant background [50]. Raddatz and Mennis [17] identify higher proportions of foreigners, as well as poor people as the main factors determining environmentally-unjust situations in cities with respect to the location of toxic release facilities. Riedel et al. [51] used two factors, the unemployment rate and mean income, to determine spatial health inequalities in the Ruhr area.

In order to understand stakeholder preferences and priorities, workshops with local stakeholders were conducted in 2014, in which the main environmental problems, as well as typical social context variables indicating inequalities in the city of Dortmund were identified. Due to the industrial development described above, the built environment, particularly in the more deprived neighborhoods, is characterized by historically-developed land use patterns exhibiting a close proximity of residential areas with other land uses, such as industrial and commercial [52]. Such mixed land use structures, though they may eventually have benefits in terms of increasing the vitality and livability of the neighborhood, are typically associated with negative environmental impacts [41]. Accordingly, noise impacts and limited air quality were identified as the main environmental stressors, while access to good quality green areas for the purposes of recreation, etc., was limited in some parts of the city. With respect to social context variables, the city has, due to its economic history, a significantly higher share of population having a background of migration, compared to the German average. In Germany, social status is still very much associated with citizenship and ethnic background [53,54]. Consequently, indicators, such as the proportion of the population with a background of migration and the proportion of families being welfare recipients, are suitable indicators of the social context of inequalities. The following indicators are therefore used in this study (Table 3).

Table 3. Selected indicators.

Indicator	Details
Migration	Inhabitants having a background of migration as a % of the total population in the neighborhood
Unemployment	Inhabitants receiving unemployment benefits as a % of the total population between 18 and 65
Welfare	Inhabitants younger than 15 and older than 65 receiving social welfare aids as a % of the total population
Socioeconomic-Disadvantage	Sum of inhabitants receiving either unemployment benefits or social welfare aids as a % of the total population
Green	Share of green area (parks and forests), >1 ha, including green areas in a 400-m zone surrounding the neighborhood, as a % of the total area of the neighborhood
Noise	Share of area having a noise impact >55 dB(A) L_{den} as a % of the total area of the neighborhood
NO ₂	Share of area having an annual average value of NO ₂ larger than or equal to 30 $\mu\text{g}/\text{m}^3$ as a % of the total area of the neighborhood
PM ₁₀	Share of area having an annual average value of PM ₁₀ larger than or equal to 25 $\mu\text{g}/\text{m}^3$ as a % of the total area of the neighborhood

The noise indicator is calculated as the percentage of the total area showing a noise impact of more than 55 db(A) resulting from any of the 5 noise sources included in this study (airport, tram, train, cars, industry). Various studies assume a significant health impact from noise exposure of more than 55 db(A) [55] (pp. 23–25). The actual noise impacts might be even higher in some areas where various noise impacts overlap, producing multiple noise impacts. Air quality in Dortmund is measured using the two most relevant substances, nitrogen dioxide (NO₂) and particulate matter (PM₁₀). As for noise emissions, the indicators are calculated as the percentage of the neighborhood where air pollution is above a certain threshold value. Germany's Federal Immission Control Act of Germany (Bundes-Immissionsschutzgesetz (BImSchG)) defines for both factors a threshold value of 40 $\mu\text{g}/\text{m}^2$ [56], while other studies suggest from a health perspective much lower values of, e.g., 20 $\mu\text{g}/\text{m}^3$ for PM₁₀, as well as various intermediate values [57]. Due to the fact that modelled air quality parameters in Dortmund for large parts of the entire city range between 21 and 40 $\mu\text{g}/\text{m}^3$, we have taken a threshold value of 30 $\mu\text{g}/\text{m}^3$ for NO₂ and 25 $\mu\text{g}/\text{m}^3$ for PM₁₀ into account based on the distribution of values over the city in order to determine intra-urban differences. Calculating the indicator as a neighborhood-wide average means that in specific locations, e.g., close to main roads, values might even be much higher.

The indicator green areas summarizes the proportion of green areas as a percentage of the entire neighborhood. As such, the indicator focuses on the availability of green areas, while aspects of the accessibility and quality of the area are not taken into account. All green areas and parks, as well as forest areas having a size of more than 1 ha, being the minimal size for having relevant functions, are included in the indicator calculation. Assuming an accessibility of green areas within a 400-m Euclidian distance [58], green areas in adjacent neighborhoods are also taken into account for the indicator calculation.

All social context indicators are calculated as a percentage of the total population in the neighborhood. The two indicators of employment and welfare measure complementary issues of interest, namely the unemployed people plus the welfare subsidies paid for the non-working share of the population, namely elderly, children and young people. Hence, the indicator of socioeconomic disadvantage is an aggregate of both indicators, indicating the total number of inhabitants with welfare needs.

3. Results

In the following section, socioeconomically-driven environmental inequalities relevant for health in the neighborhoods of Dortmund will be analyzed based on the indicators discussed above. In doing so, we first analyze associations between social context indicators and their spatial distribution. We then carry out a similar analysis of the environmental indicators, including an analysis of multiple environmental burdens. Finally, we consider the exposure of neighborhoods with significant proportions of socioeconomically-disadvantaged residents and higher levels of environmental burdens, in order to identify spatially the hotspots of environmental health-related inequalities.

3.1. Social Context Indicators

Regarding the social context determinants of health, we see a strong positive correlation between all four selected indicators (Table 4). The indicator migration is strongly correlated with both the unemployment and the welfare indicator, confirming the observation that neighborhoods with a higher proportion of residents with a background of migration are more likely to have a higher proportion of socioeconomically-disadvantaged residents. The combined indicator of socioeconomic disadvantage, that integrates working age people with the elderly and children, also correlates strongly with the migration indicator, confirming that a proportion of deprived population exists over all generations. As the combined indicator of socioeconomically disadvantaged is the most comprehensive social context indicator, we use this one in the exposure analysis below.

Table 4. Spearman rank correlation coefficients between social context indicators.

Indicators	Migration	Unemployment	Welfare	Socioeconomic Disadvantage
Migration	1.00000	0.85655 *	0.77527 *	0.86507 *
Unemployment	0.85655 *	1.00000	0.81576 *	0.98965 *
Welfare	0.77527 *	0.81576 *	1.00000	0.86939 *
Socioeconomic disadvantage	0.86507 *	0.98965 *	0.86939 *	1.00000

* p -value < 0.05.

The spatial distribution of the social context indicator socioeconomically disadvantaged on the basis of neighborhoods (Figure 2) shows that the northern part of Dortmund has a much higher share of socioeconomically-disadvantaged neighborhoods than the southern part. Almost all urban neighborhoods in the northern half, i.e., north of the central business district (CBD), fall into categories of a high to a very high proportion of socioeconomically disadvantaged. South of the CBD, only one cluster of neighborhoods in the district of Hörde is very highly disadvantaged. In contrast, the cluster of urban neighborhoods directly south of the CBD shows a medium to low share of socioeconomically disadvantaged in all neighborhoods.

However, the neighborhood having in absolute terms the highest share of socioeconomically disadvantaged is the neighborhood of Clarenberg in the district Hörde south of the inner city with a share of 36.6 percent of all people receiving some kind of welfare aid. The vast majority of other high scoring neighborhoods with values of around 30% are concentrated in the district Innenstadt Nord north of the CBD. The majority of neighborhoods scoring low in terms of socioeconomically disadvantaged are concentrated in the suburban districts of the urban periphery.

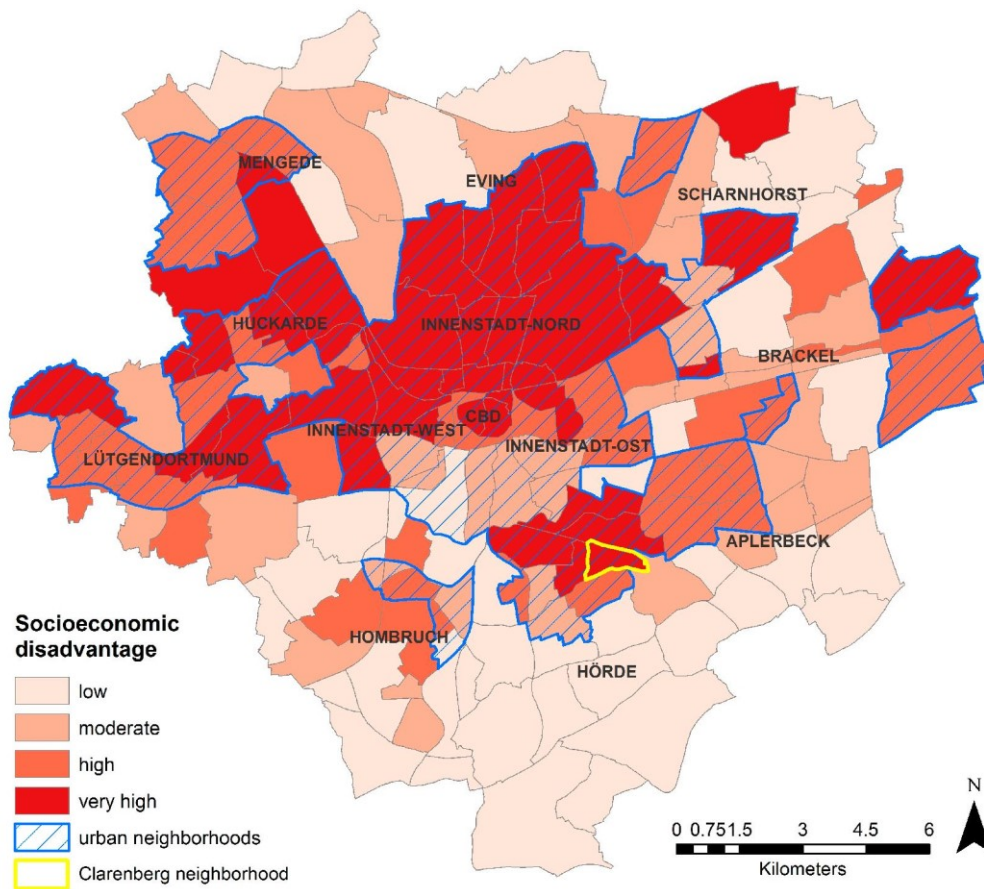


Figure 2. Proportion of socioeconomically-disadvantaged residents per neighborhood.

3.2. Environmental Indicators

The relationships between the various environmental indicators included in the study show a slightly less homogeneous, but no less significant picture (Table 5). The noise impact indicator correlates moderately positively with the two air quality indicators of PM₁₀ and NO₂, i.e., neighborhoods having a high impact in terms of noise also show significant levels of NO₂ and PM₁₀. This is not particularly surprising, as all three state indicators are at least partially affected by the same driver, namely motorized transport. While four of the five sources of noise combined in the indicator are transport related (car, tram, train, airport), 54.3% of all NO₂ emissions and 60% of PM₁₀ emissions are related to road traffic [45]. All three indicators correlate slightly less and significantly negatively with the green indicator, indicating that neighborhoods having an impact of air, as well as noise pollution also suffer from having a lower share of green areas available.

Table 5. Spearman rank correlation coefficients between environmental indicators.

Indicators	Green	Noise	NO ₂	PM ₁₀
Green	1.00000	-0.15649 *	-0.23524 *	-0.17371 *
Noise	-0.15649 *	1.00000	0.42975 *	0.49360 *
NO ₂	-0.23524 *	0.42975 *	1.00000	0.81598 *
PM ₁₀	-0.17371 *	0.49360 *	0.81598 *	1.00000

* p-value < 0.05.

The maps shown in Figure 3 exemplify spatial variations concerning the analyzed indicators. Regarding the availability of green areas the most southerly neighborhoods do somewhat better (Figure 3a). In particular, the suburban neighborhoods are much better equipped with green areas, here mainly in the form of urban forests. However, various neighborhoods to the north of the CBD also seem to benefit from a good supply of green areas, e.g., in terms of parks. With respect to NO₂, the entire central area is very badly affected (Figure 3b), which is very similar to other, comparable German cities, e.g., Berlin [59]. In particular, the neighborhoods around the main highway B1, which cuts through the central areas of Dortmund more or less straight from west to east, are highly impacted. With respect to PM₁₀, the situation is similar (Figure 3c), but with a stronger focus in the area to the northwest of the CBD. This area is where the remaining industrial areas in Dortmund are concentrated. Finally, the distribution of noise impacts (Figure 3d) indicates a much more diversified and heterogeneous picture, which is similar to patterns disclosed in other German cities [49]. The industrial neighborhoods west of the CBD stand out as having high noise impacts, as do the neighborhoods along the main highway B1 and A45 in the west (going north to south). Additionally, various urban and suburban neighborhoods reveal high to very high noise impact levels due to local noise sources.

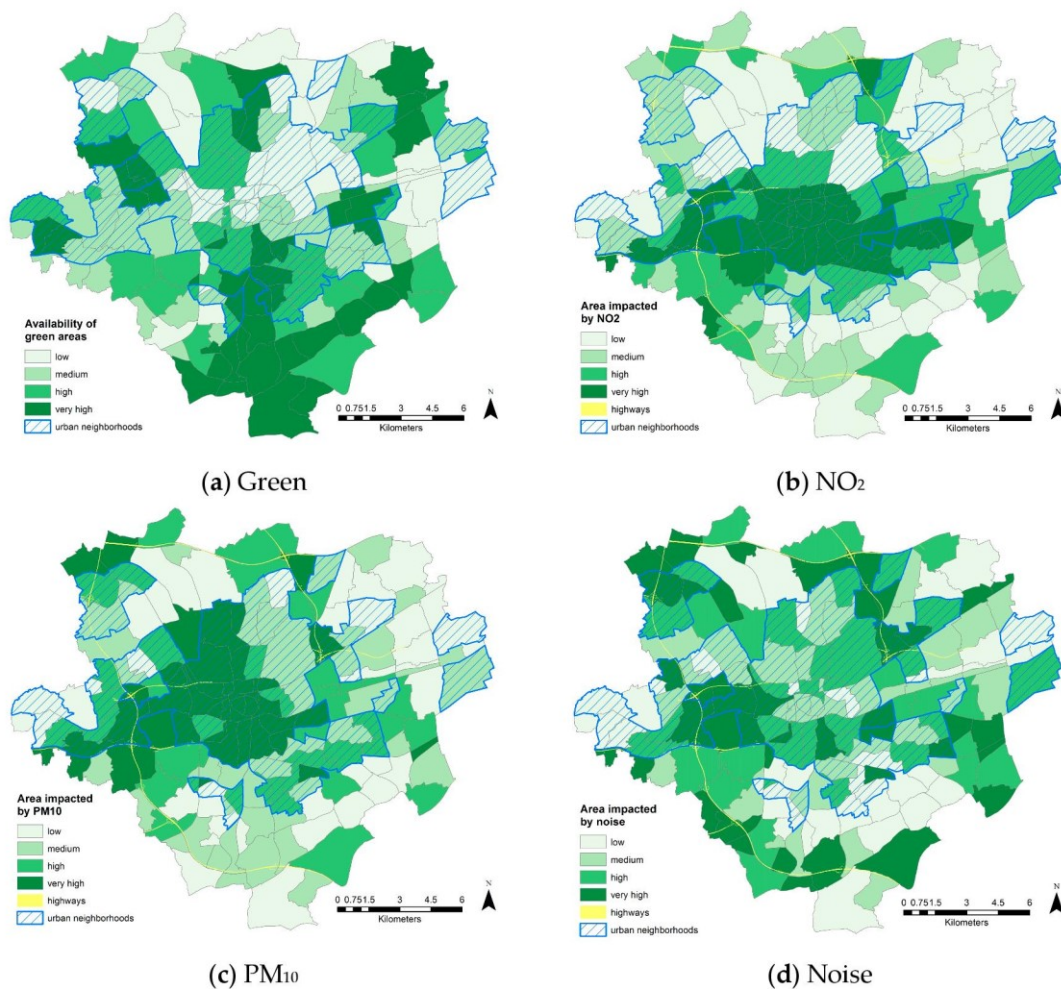


Figure 3. Maps of the four environmental indicators: (a) proportion of green areas per neighborhood; (b) proportion of area having an annual average NO₂ level $\geq 30 \mu\text{g}/\text{m}^3$; (c) proportion of area having an annual average PM₁₀ $\geq 25 \mu\text{g}/\text{m}^3$; (d) proportion of area having a noise impact $>55 \text{ dB(A)} L_{\text{den}}$.

Areas of multiple burdens are neighborhoods where the majority of environmental factors included in the study score high. Figure 4 shows the combination of the four selected environmental indicators. The factor green, being shown above as an environmental benefit, is used here in reverse order indicating a neighborhood of high availability of green with a score of four. The results show that the neighborhoods north of the CBD have the highest levels of multiple environmental burdens, together with the industrialized area west of the city. The neighborhoods scoring highest northeast of the inner city are all areas highly affected by motorized transport.

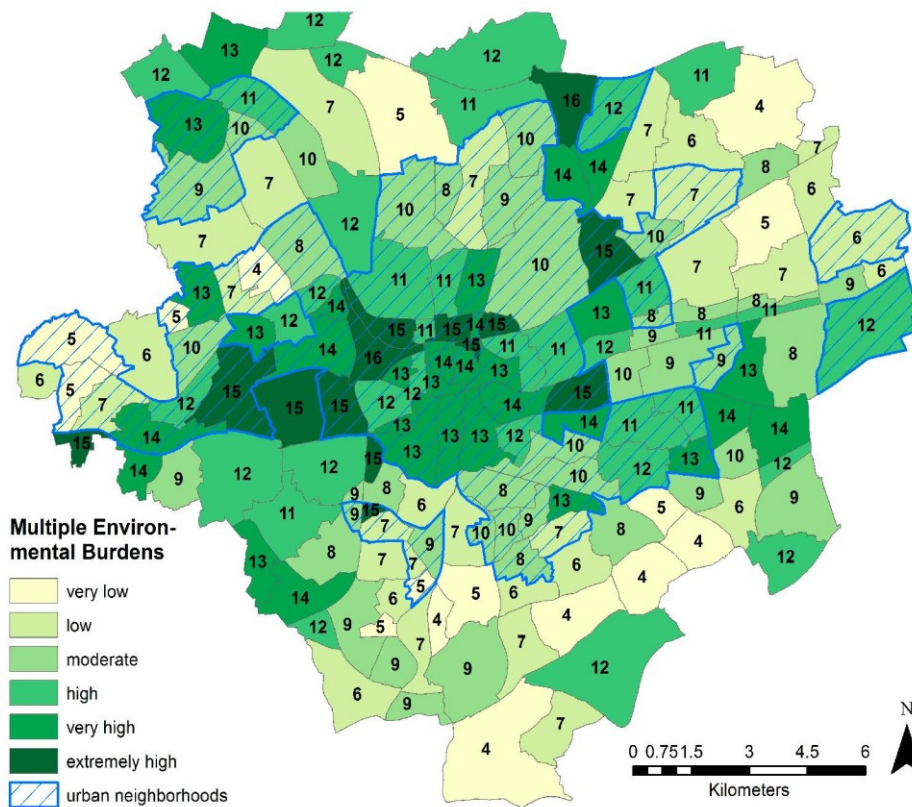


Figure 4. Multiple environmental burdens.

3.3. Exposure: Environmental Inequalities Relevant for Health

In order to identify hotspots of socioeconomically-driven environmental health inequalities, we relate the social context indicator of socioeconomically disadvantaged to the various relevant environmental indicators we have measured (Table 6). The social context indicator correlates moderately negatively with the green indicator, indicating that in areas with a higher share of socioeconomically-disadvantaged residents, less green areas are available. Further, we see a moderately positive correlation between socioeconomically disadvantaged and the two air quality indicators of PM_{10} and NO_2 . All three associations support the hypothesis that the neighborhoods of Dortmund containing higher proportions of socioeconomically-disadvantaged residents suffer from a lower environmental quality compared to the better off areas. Only the noise indicator does not significantly correlate with the social context, indicating that noise is a ubiquitous problem in Dortmund that does not distinguish between the affluent and the disadvantaged.

Table 6. Spearman rank correlation coefficients between neighborhood socioeconomic disadvantage and environmental indicators.

Indicator	Green	Noise	NO ₂	PM ₁₀
Socioeconomic disadvantage	−0.279 *	−0.01652	0.31980 *	0.25658 *

* *p*-value <0.05.

The disproportionate supply of environmental goods and bads between neighborhoods of Dortmund having a different socioeconomic profile becomes obvious when considering the spatial pattern of the distribution. Figure 5 relates neighborhoods categorized into four classes according to their share of disadvantaged inhabitants to classes of environmental quality using the PM₁₀ indicator as an example. Almost 60% of the neighborhoods having a low PM₁₀ level also have a low to medium level of deprivation. In total, 47 neighborhoods of 170 score low to medium for both indicators, PM₁₀ and socioeconomically disadvantaged. On the other hand, almost 65% of the neighborhoods showing a very high level of PM₁₀ also have a high to very high share of socioeconomically-disadvantaged inhabitants. The difference in proportions is significant (*p*-value < 0.01). Relationships between neighborhood deprivation and NO₂ and green areas were significant, as well (*p*-value < 0.01). Neighborhoods with a higher proportion of socioeconomically-disadvantaged residents were more exposed to higher NO₂ levels and had less availability of green space. There was no significant difference in proportions between deprivation and noise.

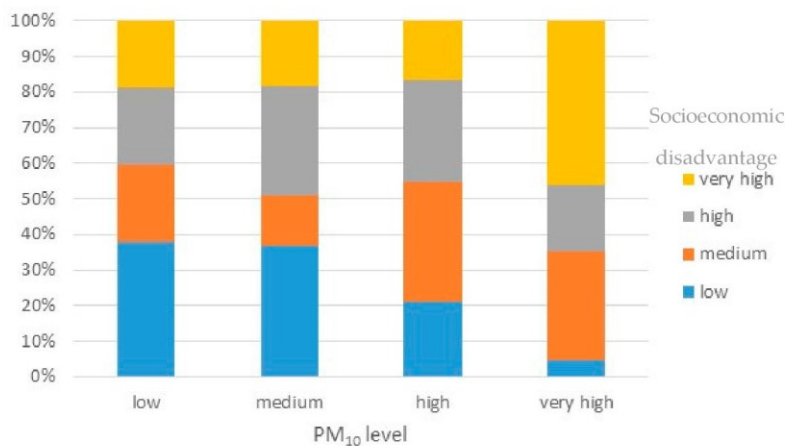


Figure 5. Proportion of socioeconomically-disadvantaged inhabitants per neighborhood in quartiles vs. the proportion of area per neighborhood impacted by PM₁₀ above the 25 µg/m³ annual mean in quartiles.

The visualization of the exposure in the form of relationships between social context indicators and environment indicators allows the spatial targeting of hotspots of environmental inequalities relevant for health. In Figure 6, the map of multiple environmental burdens is matched with four classes of socioeconomic disadvantage ranging from low to very high (in red dots). Four hotspots of environmental inequalities having the highest proportions of socioeconomically disadvantaged, as well as of cumulative environmental burdens can be identified from this map; the four neighborhoods of the Nordstadt directly north of the CBD, a cluster of neighborhoods west of the inner city, which has already been identified as a rather industrial area, and the neighborhood of Alt-Scharnhorst northeast of the inner city. While other areas scoring highest on multiple burdens show a lower level of deprivation, areas with the highest level of deprivation like the northern parts of the Nordstadt or the District of Hörde southeast of the inner city score modestly in terms of the environmental quality.

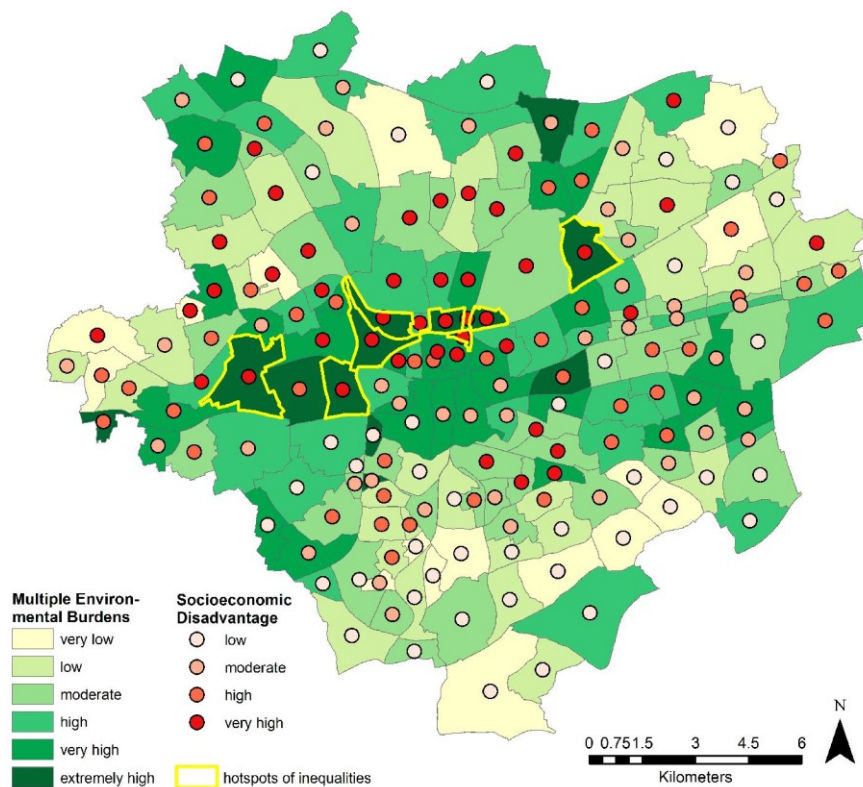


Figure 6. Hotspots of socioeconomically-driven environmental health inequalities: multiple environmental burdens and the proportion of socioeconomically-disadvantaged residents per neighborhood.

4. Discussion

The results reveal that certain neighborhoods of Dortmund facing significantly higher impacts from environmental burdens also house significantly larger proportions of inhabitants of lower socioeconomic position. Similar results have been obtained from other studies in comparable cities and regions of Germany. Riedel et al. [51] (p. 88), e.g., determine for the Ruhr region, which Dortmund is a part of, “that individuals with social risks associated with a low education or a low income are more frequently affected by chemico-physical risks”, in this case air pollutants ($PM_{2.5}$) and noise exposure. The geographical pattern of environmental inequalities as derived in this study is comparable to findings from Shrestha et al. [60] for the same city, who locate strong inequalities predominantly in the northern part of the urban core of the city.

Measuring environmental inequalities relevant for health in the form of indicators represents a useful and easy to replicate approach, especially as working with indicators is common practice in both public health and urban planning [61]. In particular, developing small-scale indicators at a neighborhood level allows the detection of areas of significant inequalities spatially. Moreover, the development of the indicators is based on data that municipalities often collect regularly or that are relatively easy to obtain. Therefore, the approach presented here is relatively easy to replicate. Finally, defining indicators based on existing environmental standards and threshold values, e.g., 55 L_{den} db(A) of noise, allows the application of the model in different political and legislative contexts and offers the possibility of testing different scenarios by varying given standards.

Corburn rightly points to the limitation of indicator-based approaches, saying that “cross sectional measures of single built and social environmental features of urban neighborhoods, tend to ignore the cascading and relational effects of inequalities in urban areas” [61] (p. 23). In a similar manner, it needs to be acknowledged that the indicators used do not necessarily measure all aspects relevant

for health. The indicator green areas for instance focusses on the availability of green areas, while the aspects of the accessibility and quality of the area are not taken into account in this analysis. Finally, the study does not include any indicators on the availability of healthcare services and infrastructures, such as hospitals or welfare facilities, which also influence health-related inequalities [62].

Further limitations of the study are that by summarizing several environmental indicators, homogenous impacts on health are assumed per unit, and by using aggregated data for environmental factors, we cannot link levels of exposure to where people live within a neighborhood. Another limitation is the assumption of the spatial homogeneity of the relationships between variables across the study area [63]. Various scholars have recently applied methods like geographically-weighted regression (GWR) to investigate spatial variations in the relationships between predictors, such as environmental or socioeconomic factors, and health outcome variables, such as childhood obesity or physical activity [64,65].

A potential source of uncertainty is the scale of the analysis, particularly the size and assumed homogeneity of the neighborhoods. In order to investigate heterogeneities within our study sample, we performed a correlation analysis separately for urban ($n = 80$) and suburban neighborhoods ($n = 90$). Both analyses yielded very similar results for the correlation as the global analysis; hence, we can assume that spatial heterogeneities are negligible. Additionally, the temporal resolution of the dataset is a potential source of uncertainties for the analysis. While most of the data are from the years 2013 to 2014, the air quality indicators are modelled using base data from 200 to 2012. Hence, the air quality indicators bear a slightly higher level of uncertainty.

The analysis of environmental inequalities relevant for health aimed to identify entry points for urban planning interventions targeting increased urban health equity. The results presented in Section 3 revealed spatial patterns of inequalities across the entire city. These helped to identify hotspots of exposure that might lead to negative health impacts, i.e., neighborhoods with significant proportions of inhabitants of lower socioeconomic position were exposed to disproportionate environmental burdens.

The toolbox of urban planning provides different instruments of planning, i.e., specific, more or less judicially formalized and institutionalized plans and procedures that can be implemented in any city. These instruments may address the existing built up area or the development of new infrastructure. As shown in Section 3, several of the identified environmental burdens we identified resulted from transport and industrial activities; others from a lack of access to green areas. Accordingly, transport planning and green space management are relevant sectoral fields of urban planning. Suitable planning instruments addressing existing built-up areas focus on the physical environment based on environmental planning law. The reduction of noise and air emissions is dealt with in instruments that are based on EU legislation, namely the EU noise directive [66] and the EU clean air directive [67]. Both have been implemented in Germany in the Federal Immission Control Act.

However, neither clean air action planning nor noise reduction planning require consideration of peoples' vulnerability or aspects of equity [68]. Currently, only existing environmental standards and the results of participation procedures are used as the basis for identifying points of intervention. In practice, this means that both planning instruments are likely to be implemented in areas showing higher levels of environmental burdens, particularly where residents do have the capacity to raise their concerns, but not necessarily in areas with higher shares of socioeconomically-disadvantaged residents. The results of the analysis shown above could be used as an additional criterion to target intervention areas and to prioritize suitable actions.

Urban planning also provides health-promoting instruments, such as green space management. Existing green space management could focus on the identified neighborhoods of low green space availability, taking the additional burden of noise into account. The assignment of quiet areas is an element of noise action planning and could be merged with green space management, especially in those areas facing noise burden.

Furthermore, the Federal Building Code of Germany includes the "Social City" program, which pays particular attention to the built environment in deprived neighborhoods. To date, the identification and delineation of target areas has mainly been guided by social indicators. Using the

results of the above analysis may help to strengthen health aspects in the selection of target areas [69]. As the program is institutionalized in the Federal Building Code, which demands not only a healthy urban development, but also that land use is socially just, it also provides a good basis for the integration of health and equity aspects.

5. Conclusions

The aim of this paper was to map socioeconomically-driven environmental inequalities relevant for health at the neighborhood level in order to identify options for concrete planning interventions. The analysis of the City of Dortmund revealed that various hotspots of environmental inequalities exist within the city. All selected socioeconomic indicators correlated quite strongly and helped to identify specific neighborhoods that house a significantly higher proportion of residents of a lower socio-economic position. We further found significant associations between the selected environmental indicators resulting in cumulative environmental burdens in various neighborhoods. Finally, we mapped levels of exposure by combining environmental state and social context indicators. The neighborhoods showing significant levels of multiple environmental burdens and at the same time housing a large proportion of socioeconomically-disadvantaged residents clearly demonstrate health-related environmental inequalities.

The toolbox of urban planning includes various planning instruments that help to address issues as identified above. In particular, instruments such as clean air action planning and noise reduction planning address environmental burdens as mapped here. However, in current planning practice, these instruments do not distinguish between populations of different socioeconomic positions, failing to recognize that those of lower socioeconomic position are more vulnerable and less able to cope with environmental burdens. Accordingly, the case for considering the vulnerability of the population in planning practice [62] might be strengthened based on the analysis carried out in this paper.

Further research is needed to advance the study of health-related environmental inequalities into studying environmental justice issues, because this requires an additional analysis of the severity, consequences or morality of the inequalities [18]. This entails the evaluation of the magnitude of the uneven distribution of environmental burdens and amenities [15]. Another challenging research issue is the assessment of cumulative environmental impacts. Going beyond the pure overlaying or adding up of multiple burdens indicating a spatial and temporal concurrence necessitates, among other things, the assessment of combined and synergetic effects of multiple environmental stressors [70]. Finally, it would be interesting to study the impacts of proposed interventions in terms of reduced inequalities in the long run. Although intra-urban socioeconomic patterns are affected by various and even contradicting trends and developments from the sub-city to the national and European level, the indicator framework as developed in this study might as well be used for a long-term panel analysis for this purpose.

Supplementary Materials: The following are available online at www.mdpi.com/www.mdpi.com/1660-4601/13/7/711/s1, Table S1. Original indicator values for 170 neighborhoods. Table S2. Reclassified indicators into quartiles.

Acknowledgments: Steffen Andreas Schüle receives a doctoral scholarship within the framework of the Junior Research Group Salus, which is funded by the foundation “Fritz und Hildegard Berg-Stiftung” within the “Stifterverband für die Deutsche Wissenschaft e.V.”, Essen, Germany. The authors would like to thank Jufo-Salus (Junior Research Group “The City as healthy living environment independent of social inequalities”): Technical University Dortmund, Faculty of Spatial Planning, Department of Urban and Regional Planning, Dortmund, Germany (Sabine Baumgart, Heike Köckler, Andrea Rüdiger, Raphael Sieber, Lisa Waegerle); University of Bremen, Faculty of Human and Health Sciences, Institute for Public Health and Nursing Research, Department of Social Epidemiology, Bremen, Germany (Gabriele Bolte, Ursula Hemetek, Steffen Schüle); University of Applied Sciences Fulda, Faculty of Caring and Health, Public Health Institute, Department of Health Promotion, Fulda, Germany (Beate Blättner, Ursula Hemetek); University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC), Department of Urban and Regional Planning and Geo-Information Management, Enschede, Netherlands (Johannes Flacke, Rehana Shrestha). We thank the City of Dortmund for providing the spatial and statistical datasets used in this study within the cooperation agreement for Jufo-Salus. Finally, we thank the anonymous reviewers for providing useful comments in order to improve the paper.

Author Contributions: Johannes Flacke initiated and designed the study, wrote the text, calculated the indicators and developed the maps and figures. Steffen Andreas Schüle performed the statistical analysis and contributed to the text. Heike Köckler contributed to the text and wrote the discussion on planning relevance. Gabriele Bolte contributed to the text and provided advice for health impacts.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Corburn, J.; Cohen, A.K. Why we need urban health equity indicators: Integrating science, policy, and community. *PLoS Med.* **2012**, *9*, 1–6. [[CrossRef](#)] [[PubMed](#)]
2. Commission on Social Determinants of Health (CSDH). *Closing the Gap in a Generation: Health Equity through Action on the Social Determinants of Health—Final Report*; WHO: Geneva, Switzerland, 2008.
3. Bernard, P.; Charafeddine, R.; Frohlich, K.L.; Daniel, M.; Kestens, Y.; Potvin, L. Health inequalities and place: A theoretical conception of neighborhood. *Soc. Sci. Med.* **2007**, *65*, 1839–1852. [[CrossRef](#)] [[PubMed](#)]
4. Diez Roux, A.V. Bringing context back into epidemiology: Variables and fallacies in multilevel analysis. *Am. J. Public Health* **1998**, *88*, 216–222. [[CrossRef](#)] [[PubMed](#)]
5. Diez Roux, A.V. A glossary for multilevel analysis. *J. Epidemiol. Commun. Health* **2002**, *56*, 588–594. [[CrossRef](#)]
6. Duncan, C.; Jones, K.; Moon, G. Context, composition and heterogeneity: Using multilevel models in health research. *Soc. Sci. Med.* **1998**, *46*, 97–117. [[CrossRef](#)]
7. Macintyre, S.; Ellaway, A.; Cummins, S. Place effects on health: How can we conceptualise, operationalise and measure them? *Soc. Sci. Med.* **2002**, *55*, 125–139. [[CrossRef](#)]
8. Ding, D.; Sallis, J.F.; Kerr, J.; Lee, S.; Rosenberg, D.E. Neighborhood environment and physical activity among youth a review. *Am. J. Prev. Med.* **2011**, *41*, 442–455. [[CrossRef](#)] [[PubMed](#)]
9. Feng, J.; Glass, T.A.; Curriero, F.C.; Stewart, W.F.; Schwartz, B.S. The built environment and obesity: A systematic review of the epidemiologic evidence. *Health Place* **2010**, *16*, 175–190. [[CrossRef](#)] [[PubMed](#)]
10. Pickett, K.E.; Pearl, M. Multilevel analyses of neighborhood socioeconomic context and health outcomes: A critical review. *J. Epidemiol. Commun. Health* **2001**, *55*, 111–122. [[CrossRef](#)]
11. Riva, M.; Gauvin, L.; Barnett, T.A. Toward the next generation of research into small area effects on health: A synthesis of multilevel investigations published since July 1998. *J. Epidemiol. Commun. Health* **2007**, *61*, 853–861. [[CrossRef](#)] [[PubMed](#)]
12. Van Holle, V.; Deforche, B.; van Cauwenberg, J.; Goubert, L.; Maes, L.; van de Weghe, N.; de Bourdeaudhuij, I. Relationship between the physical environment and different domains of physical activity in European adults: A systematic review. *BMC Public Health* **2012**. [[CrossRef](#)] [[PubMed](#)]
13. Voigtlander, S.; Berger, U.; Razum, O. The impact of regional and neighborhood deprivation on physical health in Germany: A multilevel study. *BMC Public Health* **2010**. [[CrossRef](#)] [[PubMed](#)]
14. Bolte, G.; Voigtländer, S.; Razum, O.; Mielck, A. Modelle zur Erklärung des Zusammenhangs zwischen sozialer Lage, Umwelt und Gesundheit. In *Umweltgerechtigkeit: Chancengleichheit bei Umwelt und Gesundheit: Konzepte, Datenlage und Handlungsperspektiven*, 1st ed.; Bolte, G., Bunge, C., Hornberg, C., Köckler, H., Mielck, A., Eds.; H. Huber: Bern, Switzerland, 2012; pp. 39–50.
15. Barzyk, T.M.; White, B.M.; Millard, M.; Martin, M.; Perlmutter, L.D.; Harris, F.; Nguyen, P.; Walts, A.; Geller, A. Linking socio-economic status, adverse health outcome, and environmental pollution information to develop a set of environmental justice indicators with three case study applications. *Environ. Justice* **2011**, *4*, 171–177. [[CrossRef](#)]
16. Todd, H.; Zografos, C. Justice for the environment: Developing a set of indicators of environmental justice for Scotland. *Environ. Values* **2005**, *14*, 483–501. [[CrossRef](#)]
17. Raddatz, L.; Mennis, J. Environmental justice in Hamburg, Germany. *Prof. Geogr.* **2013**, *65*, 495–511. [[CrossRef](#)]
18. Walker, G.P. *Environmental Justice: Concepts, Evidence and Politics*; Routledge: London, UK; New York, NY, USA, 2012.
19. Diez Roux, A.V.; Mair, C. Neighborhoods and health. *Ann. N. Y. Acad. Sci.* **2010**, *1186*, 125–145. [[CrossRef](#)] [[PubMed](#)]
20. Barton, H.; Grant, M. Urban planning for healthy cities: A review of the progress of the European healthy cities programme. *J. Urban Health* **2013**, *90*, 129–141. [[CrossRef](#)] [[PubMed](#)]

21. Gelormino, E.; Melis, G.; Marietta, C.; Costa, G. From built environment to health inequalities: An explanatory framework based on evidence. *Prev. Med. Rep.* **2015**, *2*, 737–745. [[CrossRef](#)] [[PubMed](#)]
22. Bambra, C.; Gibson, M.; Sowden, A.; Wright, K.; Whitehead, M.; Petticrew, M. Tackling the wider social determinants of health and health inequalities: Evidence from systematic reviews. *J. Epidemiol. Community Health* **2010**, *64*, 284–291. [[CrossRef](#)] [[PubMed](#)]
23. Braubach, M.; Grant, M. Evidence review on the spatial determinants of health in urban settings. In *Urban Planning, Environment and Health: From Evidence to Policy Action—Meeting Report*; WHO Regional Office for Europe: Copenhagen, Denmark, 2010; pp. 25–90.
24. NSW Department of Health. *Healthy Urban Development Checklist: A Guide for Health Services When Commenting on Development Policies, Plans and Proposals*; NSW Department of Health: North Ryde BC, NSW, Australia, 2009.
25. Abernethy, P. Bridging conceptual “silos”: Bringing together health promotion and sustainability governance for practitioners at the landscape scale. *Local Environ.* **2014**, *21*, 1–25. [[CrossRef](#)]
26. Lowe, M.; Whitzman, C.; Badland, H.; Davern, M.; Aye, L.; Hes, D.; Butterworth, I.; Giles-Corti, B. Planning healthy, liveable and sustainable cities: How can indicators inform policy? *Urban Policy Res.* **2015**, *33*, 131–144. [[CrossRef](#)]
27. Friel, S.; Akerman, M.; Hancock, T.; Kumaresan, J.; Marmot, M.; Melin, T.; Vlahov, D. Addressing the social and environmental determinants of urban health equity: Evidence for action and a research agenda. *J. Urban Health* **2011**, *88*, 860–874. [[CrossRef](#)] [[PubMed](#)]
28. WHO. *Environmental Health Indicators. Framework and Methodologies*; WHO: Geneva, Switzerland, 1999.
29. WHO & UN Habitat. *Hidden Cities: Unmasking and Overcoming Health Inequities in Urban Settings*; WHO & UN Habitat: Kobe, Japan, 2010.
30. Fairburn, J.; Smith, G. *Working towards a Better Quality of Life: Environmental Justice in South Yorkshire*; Leeds: West Yorkshire, UK, 2008.
31. Rothenberg, R.; Weaver, S.R.; Dai, D.; Stauber, C.; Prasad, A.; Kano, M. A flexible urban health index for small area disparities. *J. Urban Health* **2014**, *91*, 823–835. [[CrossRef](#)] [[PubMed](#)]
32. Prasad, A.; Kano, M.; Dagg, K.A.-M.; Mori, H.; Senkoro, H.H.; Ardakani, M.A.; Elfeky, S.; Good, S.; Engelhardt, K.; Ross, A.; et al. Prioritizing action on health inequities in cities: An evaluation of urban health equity assessment and response tool (Urban HEART) in 15 cities from Asia and Africa. *Soc. Sci. Med.* **2015**, *145*, 237–242. [[CrossRef](#)] [[PubMed](#)]
33. Flacke, J.; Köckler, H. Spatial urban health equity indicators—A framework-based approach supporting spatial decision making. In *Sustainable Development and Planning VII*; Özçevik, Ö., Brebbia, C., Şener, S., Eds.; Wit Press: Southampton, UK, 2015; pp. 365–376.
34. Morris, G.; Beck, S.; Hanlon, P.; Robertson, R. Getting strategic about the environment and health. *Public Health* **2006**, *120*, 889–903. [[CrossRef](#)] [[PubMed](#)]
35. Hambling, T.; Weinstein, P.; Slaney, D. A review of frameworks for developing environmental health indicators for climate change and health. *Int. J. Environ. Res. Public Health* **2011**, *8*, 1–22. [[CrossRef](#)] [[PubMed](#)]
36. Alexeeff, G.V.; Faust, J.B.; August, L.M.; Milanese, C.; Randles, K.; Zeise, L.; Denton, J. A screening method for assessing cumulative impacts. *Int. J. Environ. Res. Public Health* **2012**, *9*, 648–659. [[CrossRef](#)] [[PubMed](#)]
37. Baden, B.M.; Noonan, D.S.; Turaga, R.M.R. Scales of justice: Is there a geographic bias in environmental equity analysis? *J. Environ. Plan. Manag.* **2007**, *50*, 163–185. [[CrossRef](#)]
38. Stadt Dortmund. *Gebietstypisierung: Am Beispiel der 170 statistischen Unterbezirke in Dortmund*; Stadt Dortmund: Dortmund, Germany, 2010.
39. Stadt Dortmund. *Statistikatlas Dortmunder Stadtteile: Dortmunder Statistik 2015*; Stadt Dortmund: Dortmund, Germany, 2015.
40. Statista GmbH. Arbeitslosenquote in Deutschland von Mai 2015 bis Mai 2016. Available online: <http://www.de.statista.com/statistik/daten/studie/1239/umfrage/aktuelle-arbeitslosenquote-in-deutschland-monatsdurchschnittswerte/> (accessed on 12 June 2016).
41. Köckler, H.; Blaettner, B.; Bolte, G.; Flacke, J.; Ruediger, A.; Baumgart, S. Gesundheitsfördernde Stadtentwicklung für alle: Gemeinsam den Bestand entwickeln. *UMID* **2014**, *2*, 23–29.
42. Strohmeier, K.; Bader, S. Demographic Decline, Segregation, and Social Urban Renewal in Old Industrial Metropolitan Areas. 2016. Available online: <http://www.difu.de/publikationen/demographic-decline-segregation-and-social-urban-renewal-in.html> (accessed on 1 July 2016).

43. Salus, J.-F. Gesunde Staedte fuer alle: Gemeinsame Strategien von Stadtplanung und Public Health. *Planerin* **2012**, *5*, 47–48.
44. Umgebungslaerm in NRW. Available online: www.umgebungslaerm.nrw.de (accessed on 11 July 2016).
45. simuPLAN. *Modellgestützte Ermittlung der Immissionsbeiträge aller relevanten Quellgruppen für das Stadtgebiet von Dortmund: Ergebnisbericht*; Stadt Dortmund: Dorsten, Germany, 2013.
46. New Insights into the Ruhr Region. Available online: <http://www.metropoleruhr.de/en/start/> (accessed on 11 July 2016).
47. Hinkel, J. “Indicators of vulnerability and adaptive capacity”: Towards a clarification of the science-policy interface. *Glob. Environ. Chang.* **2011**, *21*, 198–208. [[CrossRef](#)]
48. WHO Regional Office for Europe. *Urban Planning, Environment and Health: From Evidence to Policy Action—Meeting Report*; World Health Organization: Copenhagen, Denmark, 2010.
49. Lakes, T.; Brückner, M.; Krämer, A. Development of an environmental justice index to determine socio-economic disparities of noise pollution and green space in residential areas in Berlin. *J. Environ. Plan. Manag.* **2013**, *57*, 538–556. [[CrossRef](#)]
50. Welsch, J.; Bömermann, H.; Nagel, H. Data Sources of the Berlin Pilot Project: The Berlin Environmental Atlas and Social Urban Development Monitoring. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/515/publikationen/umid0211_0.pdf (accessed on 2 August 2011).
51. Riedel, N.; Hoffmann, B.; Fuks, K.; Jöckel, K.-H.; Dagano, N. Health inequalities in the city: Assessing the concurrence of social and environmental risks in the Ruhr Area. *UMID* **2011**, *2*, 85–90.
52. Von Alemann, U.; Loss, K.; Vowe, G. *Politik: Eine Einführung*; VS Verlag für Sozialwissenschaften: Wiesbaden, Germany, 1994.
53. Bruckner, E. Migration und Demographischer Wandel. Available online: https://www.bertelsmann-stiftung.de/fileadmin/files/BSt/Presse/imported/downloads/xcms_bst_dms_36564_36565_2.pdf (accessed on 24 April 2016).
54. Kristen, C.; Granato, N. The educational attainment of the second generation in Germany: Social origins and ethnic inequality. *Ethnicities* **2007**, *7*, 343–366. [[CrossRef](#)]
55. Expert Panel on Noise (EPoN). Good Practice Guide on Noise Exposure and Potential Health Effects: EEA Technical Report. Available online: <http://www.eea.europa.eu/publications/good-practice-guide-on-noise> (accessed on 9 November 2010).
56. Deutscher Bundestag Drucksache 17/ 508 17. Wahlperiode 25. 01. 2010 Verordnung der Bundesregierung Neununddreißigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über Luftqualitätsstandards und Emissionshöchstmenge—39. BImSchV). Available online: <http://dipbt.bundestag.de/dip21/btd/17/005/1700508.pdf> (accessed on 25 January 2015).
57. Schneider, J.; Nagl, C.; Schmid, B. *EU Air Quality Policy and WHO Guideline Values for Health*; European Union: Brussels, Belgium, 2014.
58. Higgs, G.; Fry, R.; Langford, M. Investigating the implications of using alternative GIS-based techniques to measure accessibility to green space. *Environ. Plan. B* **2012**, *39*, 326–343. [[CrossRef](#)]
59. Kindler, A.; Weiland, U.; Franck, U. Socio-Spatial Distribution of Ambient Air Exposure in Berlin. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/515/publikationen/umid0211_0.pdf (accessed on 2 August 2011).
60. Shrestha, R.; Flacke, J.; Martinez, J.A.; van Maarseveen, M. Environmental health related socio-spatial inequalities: Identifying ‘hotspots’ of environmental burdens and social vulnerability. *Int. J. Environ. Res. Public Health* **2016**, *13*, 1–23. [[CrossRef](#)]
61. Corburn, J. *Healthy City Planning: From Neighborhood to National Health Equity*; Routledge: New York, NY, USA, 2013.
62. WHO Centre for Health Development. *Urban HEART: Urban Health Equity Assessment and Response Tool*; World Health Organization: Kobe, Japan, 2010.
63. Chakraborty, J.; Maantay, J.; Brender, J. Disproportionate proximity to environmental health hazards: Methods, models, and measurement. *Am. J. Public Health* **2011**, *101*, S27–S36. [[CrossRef](#)] [[PubMed](#)]
64. Feuillet, T.; Charreire, H.; Menai, M.; Salze, P.; Simon, C.; Dugas, J.; Herberg, S.; Andreeva, V.A.; Enaux, C.; Weber, C.; et al. Spatial heterogeneity of the relationships between environmental characteristics and active commuting: Towards a locally varying social ecological model. *Int. J. Health Geogr.* **2015**, *14*, 1–14. [[CrossRef](#)] [[PubMed](#)]

65. Chalkias, C.; Papadopoulos, A.G.; Kalogeropoulos, K.; Tambalis, K.; Psarra, G.; Sidossis, L. Geographical heterogeneity of the relationship between childhood obesity and socio-environmental status: Empirical evidence from Athens, Greece. *Appl. Geogr.* **2013**, *37*, 34–43. [[CrossRef](#)]
66. Assessment and Management of Environmental Noise: Directive 2002/49/EC. 2002. Available online: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32002L0049> (accessed on 25 June 2002).
67. Ambient Air Quality and Cleaner Air for Europe: Directive 2008/50/EC. Available online: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0050> (accessed on 21 May 2008).
68. Köckler, H. Environmental justice—Aspects and questions for planning procedures. *UVP Rep.* **2014**, *28*, 139–142.
69. ARL. *Umwelt-und Gesundheitsaspekte im Programm Soziale Stadt—Ein Plädoyer für eine stärkere Integration: Positionspapier aus der ARL*; ARL: Hannover, Germany, 2014.
70. Sexton, K.; Linder, S.H. The role of cumulative risk assessment in decisions about environmental justice. *Int. J. Environ. Res. Public Health* **2010**, *7*, 4037–4049. [[CrossRef](#)] [[PubMed](#)]



© 2016 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Annex B Author contributions

1. **Schüle, S. A., & Bolte, G. (2015).** Interactive and independent associations between the socioeconomic and objective built environment on the neighbourhood level and individual health: A systematic review of multilevel studies. *PloS One*, *10*(4), e0123456. doi: 10.1371/journal.pone.0123456

Steffen Schüle initiated the systematic review, developed and applied the search algorithm, performed abstract screening and full text analysis, and wrote the main text. Gabriele Bolte contributed to the methods and helped to draft the manuscript.

2. **Schüle, S. A., von Kries, R., Fromme, H., & Bolte, G. (2016).** Neighbourhood socioeconomic context, individual socioeconomic position, and overweight in young children: a multilevel study in a large German city. *BMC Obesity*, *3*, 25. doi: 10.1186/s40608-016-0106-4

Steffen Schüle performed the statistical analysis and wrote the main text. Hermann Fromme and Gabriele Bolte conceptualized the GME surveys and Gabriele Bolte was responsible for its design. Furthermore, Rüdiger von Kries, Hermann Fromme and Gabriele Bolte supported to draft the manuscript.

3. **Schüle, S. A., Fromme, H., & Bolte, G. (2016).** Built and socioeconomic neighbourhood environments and overweight in preschool aged children. A multilevel study to disentangle individual and contextual relationships. *Environmental Research*, *150*, 328-336. doi: 10.1016/j.envres.2016.06.024

Steffen Schüle performed the statistical analysis, calculated GIS based variables in ArcGIS, and wrote the main text. Hermann Fromme and Gabriele Bolte conceptualized the GME surveys and Gabriele Bolte was responsible for its design. Furthermore, Hermann Fromme and Gabriele Bolte contributed to draft the manuscript.

4. **Schüle, S.A., Gabriel, K.M.A., & Bolte, G. (2017).** Relationship between neighbourhood socioeconomic position and neighbourhood public green space availability: An environmental inequality analysis in a large German city applying generalized linear models. *International Journal of Hygiene and Environmental Health*, *in press*. doi:10.1016/j.ijheh.2017.02.006

Steffen Schüle initiated and designed the study, performed the statistical analysis, calculated GIS based variables in ArcGIS, developed the maps, and wrote the main text.

Katharina Gabriel contributed to the development of green space variables. Gabriele Bolte and Katharina Gabriel helped to draft the manuscript.

5. Flacke, J., **Schüle, S. A.**, Köckler, H., & Bolte, G. (2016). Mapping environmental inequalities relevant for health for informing urban planning interventions-A case study in the city of Dortmund, Germany. *International Journal of Environmental Research and Public Health*, 13(7). doi: 10.3390/ijerph13070711

Johannes Flacke initiated and designed the study, wrote the text, calculated the indicators and developed the maps and figures. Steffen Schüle performed the statistical analysis and contributed to the text. Heike Köckler contributed to the text and wrote the discussion on planning relevance. Gabriele Bolte contributed to the text and provided advice for health impacts.

Annex C Further publications, posters, and oral presentations

Publications

Bolte, G., **Schüle, S. A.** (2016). Welchen Beitrag kann sozialepidemiologische Forschung für eine gesundheitsfördernde Stadtentwicklung leisten? *Public Health Forum* , 24(4), 265–268. doi: 10.1515/pubhef-2016-2100

Oral presentations

Schüle, S. A. (2016). Sozialepidemiologische Methoden und Daten als Basis für Gesundheitsförderung im Raum. Sozioökonomisch benachteiligte Stadtteile, benachteiligtes Wohnumfeld, schlechte individuelle Gesundheit!? Tagung Stadt der Zukunft: Nachhaltigkeit und Gesundheit gemeinsam fördern – Neue methodische Ansätze, Dortmund, Germany, 09.06.2016

Schüle, S. A., Fromme, H., Bolte, G. (2015). Relationship between public playgrounds, individual socioeconomic position, and overweight in children. Results from a multilevel study in a large German city. 27th Conference of the International Society for Environmental Epidemiology, “Addressing Environmental Health Inequalities”, Sao Paulo, Brazil, 30.08.-03.09.2015

Schüle, S. A. (2014). Are contextual effects of the socioeconomic and objective built neighbourhood environment on individual health independent from each other? A systematic review of multilevel studies. 9. Jahrestagung der Deutschen Gesellschaft für Epidemiologie (DGEpi), Ulm, Germany, 17.-20.09.2014

Schüle, S. A., Fromme, H., Bolte, G., the Study Group of the GME cohort (2014). Kindergesundheit in München: Einflussgrößen auf mehreren Ebenen? Mehrebenenmodellierung aggregierter Daten der sozialen und gebauten Wohnumwelt sowie individueller Sozialdaten (,work in progress‘). Workshop des gemeinsamen Arbeitskreises „Umweltmedizin, Expositions- und Risikoabschätzungen“ der DGEpi, DGSMF und GMDS. Themenschwerpunkt: Mischexpositionen und Kombinationswirkungen, Munich, Germany, 15.-16.05.2014

Schüle, S. A. (2013). Arme Familien, arme Stadtteile, schlechte Wohnbedingungen?! - Gesundheitliche Mehrfachbelastungen in der gebauten und sozialen Wohnumwelt von Kindern im Kontext sozialer Ungleichheit. Fachtagung Stadtwandel als Chance - für Klima, Umwelt, Gesundheit und Lebensqualität, Wuppertal, Deutschland, 28.11.2013

Poster presentations

Schüle, S. A., Gabriel, K., Bolte, G. (2016). Relationship between neighbourhood socioeconomic position and availability of public green space applying generalized linear models. An environmental justice analysis in a large German city. 28th Conference of the International Society for Environmental Epidemiology, “Old and new risks: challenges for environmental epidemiology”, Rome, Italy, 01.-4.09.2016

Flacke, J., Bolte, G., **Schüle, S. A.**, Köckler, H. (2015). Spatial indicators for decision making to reduce urban health inequalities. 27th Conference of the International Society for Environmental Epidemiology, “Addressing environmental health inequalities”, Sao Paulo, Brazil, 30.08.-03.09.2015

Schüle, S. A., Shresta, R., Sieber, R., Waegerle, L., Hemetek, U., Bolte, G., Flacke, J., Köckler, H., Blättner, B., Baumgart, S., Rüdiger, A. (2015). Healthy cities for all!? – An interdisciplinary research group targeting at healthy living environments independent of social inequalities. 27th Conference of the International Society for Environmental Epidemiology, “Addressing environmental health inequalities”, Sao Paulo, Brazil, 30.08.-03.09.2015

Annex D Eidesstattliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Dissertation selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe, und dass alle Stellen der Arbeit, die wörtlich oder sinngemäß aus anderen Quellen übernommen wurden, als solche kenntlich gemacht sind. Des Weiteren versichere ich, dass die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegt wurde und ich bisher auch keine weiteren Versuche zur Promotion unternommen habe.

Bremen, den

(Unterschrift)