



Original Contribution

Regional and Neighborhood Disparities in the Odds of Type 2 Diabetes: Results From 5 Population-Based Studies in Germany (DIAB-CORE Consortium)

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The objective of this study was to investigate the association between residential environment and type 2 diabetes. We pooled cross-sectional data from 5 population-based German studies (1997–2006): the Cardiovascular Disease, Living and Ageing in Halle Study, the Dortmund Health Study, the Heinz Nixdorf Recall Study, the Cooperative Health Research in the Region of Augsburg Study, and the Study of Health in Pomerania. The outcome of interest was the presence of self-reported type 2 diabetes. We conducted mixed logistic regression models in a hierarchical data set with 8,879 individuals aged 45–74 years on level 1; 226 neighborhoods on level 2; and 5 study regions on level 3. The analyses were adjusted for age, sex, social class, and employment status. The odds ratio for type 2 diabetes was highest in eastern Germany (odds ratio = 1.98, 95% confidence interval: 1.81, 2.14) and northeastern Germany (odds ratio = 1.58, 95% confidence interval: 1.40, 1.77) and lowest in southern Germany (reference) after adjustment for individual variables. Neighborhood unemployment rates explained a large proportion of regional differences. Individuals residing in neighborhoods with high unemployment rates had elevated odds of type 2 diabetes (odds ratio = 1.62, 95% confidence interval: 1.25, 2.09). The diverging levels of unemployment in neighborhoods and regions are an independent source of disparities in type 2 diabetes.

diabetes mellitus; lifestyle; multilevel analysis; residence characteristics; socioeconomic factors; type 2 diabetes

Abbreviations: CARLA, Cardiovascular Disease, Living and Ageing in Halle Study; CI, confidence interval; DHS, Dortmund Health Study; DIAB-CORE, Diabetes Collaborative Research of Epidemiologic Studies; HNR, Heinz Nixdorf Recall Study; KORA, Cooperative Health Research in the Region of Augsburg; OR, odds ratio; SD, standard deviation; SE, standard error; SHIP, Study of Health in Pomerania.

To date, research on type 2 diabetes has focused mainly on individual risk factors, such as social determinants (1), health-related behaviors (2), and biological dispositions (3), whereas the role of the residential environment has rarely been studied. Most studies have concentrated on the availability of grocery stores and the supply of healthy food, which tend to be worse in poor areas (4, 5). Studies of the relationship between the residential environment and diabetes are rare, particularly those that consider the individual and contextual perspectives in a simultaneous analysis and that focus on small areas as the unit of analysis. Studies

based on aggregated data have reported increased prevalence and incidence of diabetes in economically depressed areas (6–10). In a multilevel analysis, Diez-Roux et al. (11) used data from young adults recruited for the Coronary Artery Risk Development in Young Adults (CARDIA) Study and found that insulin resistance was associated with a disadvantaged economic neighborhood environment, independent of individual social status.

Individuals' life circumstances and their health and psychological well-being are influenced by their residential environments (12). For instance, a deprived neighborhood

environment is found to be related to worse health outcomes, for example, coronary heart disease (13) and mortality (14). From a public health perspective, the analysis of spatial disparities in health outcomes helps to identify high-risk populations and settings with a high disease prevalence, which can be addressed in intervention programs (15).

In Germany, a significant southwest to northeast gradient has been reported for various health-related behaviors and diseases, including the prevalence of smoking (16), hypertension (17), obesity (18), and cardiovascular mortality (19). This study is part of the Diabetes Collaborative Research of Epidemiologic Studies (DIAB-CORE) in Germany, which uses data from 5 regional and 1 national study for pooled analysis of type 2 diabetes prevalence and incidence, regional and socioeconomic disparities in type 2 diabetes, health-related quality of life, and costs of care and medication for patients with diabetes. By using data from DIAB-CORE, Schipf et al. (20) confirmed this southwest to northeast pattern for the age-standardized prevalence of type 2 diabetes, which ranged from 5.8% in southern Germany to 12.0% in eastern Germany.

In this study, we investigated the association between residential environment and the odds of type 2 diabetes. Individual data from 5 population-based studies were pooled and combined with contextual data, which enabled us to conduct simultaneous analyses on individual, neighborhood, and regional levels. The objective was to evaluate whether neighborhood variables contribute to the explanation of disparities in type 2 diabetes at the neighborhood and regional levels when adjusted for individual variables. Furthermore, we examined the importance of individual lifestyle as a potential mediator in the association between residential environment and type 2 diabetes.

MATERIALS AND METHODS

Data

Cross-sectional data from 5 regional studies were pooled and combined with data on neighborhood characteristics of the corresponding study regions. The analysis included the Cardiovascular Disease, Living and Ageing in Halle Study (CARLA), the Dortmund Health Study (DHS), the Heinz Nixdorf Recall Study (HNR), the Cooperative Health Research in the Region of Augsburg (KORA) Survey 4, and the Study of Health in Pomerania (SHIP) (Figure 1). These population-based studies have a 2-stage cluster (SHIP and KORA) or stratified random sampling (DHS, HNR, and CARLA). Data collection was performed between 1997 and 2006 with response rates ranging between 56% and 69%. All participants gave written informed consent. The study designs have been described elsewhere in detail (21–25). To ensure comparability across studies, analyses were restricted to subjects aged 45–74 years. The total sample consisted of 11,688 subjects.

Participants' addresses of residence at baseline were used to assign them to neighborhoods according to administrative boundaries. In HNR, DHS, and CARLA, neighborhoods were defined by city districts or by statistical administrative units, which are a subdivision of city districts. In SHIP and

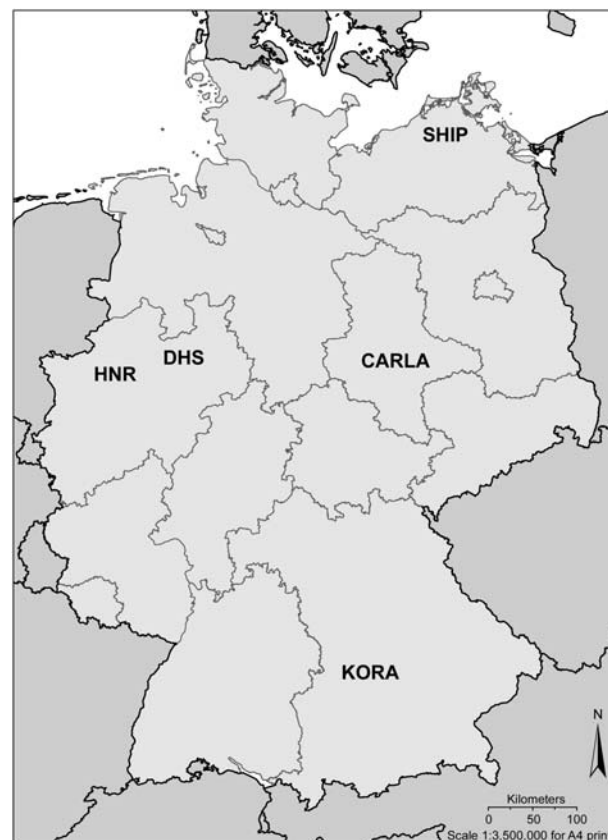


Figure 1. Map of Germany with the locations of the study regions of CARLA, DHS, KORA, HNR, and SHIP. Data sources: VG250 (GK3), German Federal Agency for Cartography and Geodesy; and Nomenclature of Statistical Territorial Units 0, Eurostat, EuroGeographics for the administrative boundaries. Cartography: Werner Maier, Helmholtz Zentrum München, 2012. CARLA, Cardiovascular Disease, Living and Ageing in Halle Study; DHS, Dortmund Health Study; HNR, Heinz Nixdorf Recall Study; KORA, Cooperative Health Research in the Region of Augsburg, Survey 4; SHIP, Study of Health in Pomerania.

KORA, our analysis was restricted to the cities within these regions (Augsburg in KORA; Stralsund and Greifswald in SHIP), which required exclusion of 2,281 individuals living in rural areas. Neighborhoods were defined on a higher level due to data privacy regulations; KORA participants were assigned to planning regions, which consist of city districts, and SHIP participants were assigned to postal code districts. Eight participants were excluded from analysis because their addresses could not be linked to neighborhoods. In this report, we will refer to statistical administrative units, planning regions, and city districts as “neighborhoods.” The 5 study regions comprised 236 neighborhoods, of which participants resided in 227. Our initial sample comprised 9,399 individuals. After exclusion of individuals with missing information on social class or employment status, the final sample consisted of 8,879 individuals in 226 neighborhoods.

Outcome variable

The investigated outcome was the presence of type 2 diabetes. We used the DIAB-CORE consortium's definition of prevalent type 2 diabetes (26). It includes self-reported, physician-diagnosed type 2 diabetes and self-reported diabetes treatment (insulin, oral antidiabetic agents, a combination of insulin and oral antidiabetic agents, or dietary treatment). Because not all studies evaluated diabetes type, subjects reporting an age at diagnosis of 30 years or younger were excluded from the analyses to avoid inclusion of possible cases of type 1 diabetes.

Neighborhood variables

The selection of context variables was based on theoretical considerations and data availability, ensuring comparability across regions. Unemployment rate (number of unemployed residents/population aged 15–64 years) is a proxy for the socioeconomic status of a neighborhood, which has commonly been used as a measure of social and material deprivation and is considered a strong predictor of health outcomes (27, 28). To capture sociodemographic aspects of neighborhoods, the number of immigrants (individuals of non-German nationality with permanent residence, according to the population registry), married residents, residents aged 0–17 years, and residents aged ≥ 65 years relative to the total number of residents were considered in our analyses (28, 29). The age and ethnic compositions of communities has been shown to affect social support networks and residents' norms and values (30).

Individual variables

Covariates in the analysis were age (continuous), sex, social class ("lower," "middle," or "higher"), and employment status ("employed," "unemployed," "retired," or "other" (those in occupational retraining or who choose not to work outside the home)). Social class was coded as a summary score of the net household income and educational attainment derived from a modified version of the Winkler Index of Socioeconomic Status (31). The dichotomized lifestyle variables of smoking status ("not current smoker" or "current smoker"), physical activity ("active" or "never active"), body mass index (measured as weight (kg)/height (m)²) (<30 or ≥ 30), and alcohol consumption ("no or moderate intake" or "high intake") were summarized in an index of health-related behaviors (32). The categories for alcohol consumption were defined as follows. For women, "no or moderate intake" represented ≤ 20 g of alcohol per day and "high intake" represented >20 g of alcohol per day. For men, "no or moderate intake" represented ≤ 40 g of alcohol per day and "high intake" represented >40 g of alcohol per day. Each unhealthy behavior was assigned 1 point, and all behaviors were summed, creating an index of health-related behaviors. The index had 5 categories, ranging from the healthiest lifestyle (0 unhealthy habits) to the least healthy lifestyle (4 unhealthy habits) and reflected an increased burden of an unhealthy lifestyle at higher levels. Due to missing information

on lifestyle, this subanalysis was based on a sample of 8,740 individuals (complete case analysis).

Statistical analysis

A series of mixed effects logistic regression models was fitted. All models had the following hierarchical structure: individuals (level 1) were nested within neighborhoods (level 2), which nested in study regions (level 3). The results are presented as odds ratios with corresponding 95% confidence intervals. The outcome variable, type 2 diabetes, was coded dichotomously.

Area-level variance (V_A) was reported as median odds ratios, a transformation of the V_A on an odds ratio scale. The median odds ratio quantifies between-cluster heterogeneity and supplies the median value of all odds ratios between a randomly chosen highest- and lowest-risk area. The median odds ratio was calculated on the neighborhood level and on the level of the 5 studies with the following equation: median odds ratio = $\exp(\sqrt{(2 \times V_A)} \times \Phi^{-1}(0.75))$, where $\Phi^{-1}(0.75)$ refers to the 75th percentile of the cumulative distribution function of a normal distribution (33, 34).

First, we fitted a baseline model adjusted for age and sex on the individual level. Second, we controlled additionally for individual social class and employment status. Third, we added the context variables to the model adjusted for individual variables, which was given as continuous measures in percent and quintiles. Quintiles were constructed on the neighborhood level within each study region. We evaluated the association between each context variable and type 2 diabetes and the contribution to the explanation of heterogeneity on the neighborhood level and regional level in separate models. Finally, the models were adjusted for neighborhood unemployment rate to control for the neighborhoods' economic status. Odds ratios and corresponding 95% confidence intervals for the study regions were predicted for each model via maximum likelihood estimation of random intercepts (35).

In a supplemental analysis, we examined the importance of individual lifestyle as a mediator in the relationship between residential environment and type 2 diabetes. A variable was identified as a mediator if it influenced the dependent variable, was affected by the independent variable, and changed the effect estimates of the independent variable on the dependent variable (36, 37). An east-west indicator was coded (dummy variable indicating eastern Germany or western Germany) to evaluate whether the selected context variables resulted in a clustering of eastern and western German regions, as shown by Voigtländer et al. (29). The model fit was assessed via likelihood ratio test. The estimations were performed by using Stata/SE, version 11.0, software (StataCorp LP, College Station, Texas).

RESULTS

Tables 1 and 2 show an overview of the characteristics of the 5 study regions and their included neighborhoods. Considerable differences existed in the magnitude of the context variables among study regions (Table 2). The median population in the 226 neighborhoods in which study participants

Table 1. Characteristics of the Regions Included in 5 Population-Based Studies^a in Germany, 1997–2006

Study	Study Period	Federal State, Region	Cities Included	Total No. of Neighborhoods in Region (Type)	No. of Neighborhoods in Which Participants Lived	Total No. of Participants (Initial/Final) ^b	No. of Participants per Neighborhood, range	Total Population of Region
CARLA	December 2002–January 2006	Saxony-Anhalt, eastern	Halle	43 (City districts)	37	1,380/1,364	3–139	238,078
DHS	September 2003–June 2004	North Rhine Westphalia, western	Dortmund	62 (Statistical administration units)	60	883/826	1–42	587,607
KORA	October 1999–April 2001	Bavaria, southern	Augsburg	17 (Planning regions)	17	1,086/1,026	13–141	252,725
HNR	December 2000–June 2003	North Rhine Westphalia, western	Bochum, Essen, Mülheim	108 (Statistical administration units)	106	4,734/4,432	1–140	1,142,112
SHIP	October 1997–March 2001	Mecklenburg-Western Pomerania, northeastern	Greifswald, Stralsund	6 (Clusters of city districts)	6	1,316/1,231	95–396	115,962

Abbreviations: CARLA, Cardiovascular Disease, Living and Ageing in Halle Study; DHS, Dortmund Health Study; HNR, Heinz Nixdorf Recall Study; KORA, Cooperative Health Research in the Region of Augsburg, Survey 4; SHIP, Study of Health in Pomerania.

^a Total population, 8,879 from the following studies: Cardiovascular Disease, Living and Ageing in Halle Study; Dortmund Health Study; Heinz Nixdorf Recall Study; Cooperative Health Research in the Region of Augsburg, Survey 4; and Study of Health in Pomerania.

^b The initial sample comprised 9,399 study participants aged 45–74 years with complete information on diabetes status and neighborhood of residence. The final sample for analysis included 8,879 study participants after the exclusion of participants with missing information on individual characteristics.

Table 2. Characteristics of Neighborhoods Included in 5 Population-Based Studies in Germany, 1997–2006

Neighborhood Characteristics	CARLA ^a			DHS ^b			KORA ^c			HNR ^d			SHIP ^e		
	Mean %	Neighborhood Range		Mean %	Neighborhood Range		Mean %	Neighborhood Range		Mean %	Neighborhood Range		Mean %	Neighborhood Range	
		%	No.		%	No.		%	No.		%	No.		%	No.
Population			18–19,210			476–25,686			2,730–37,246			262–32,466			5,230–31,154
Unemployment rate	14.1	3.9–22.5		15.3	5.0–27.7		4.8	1.9–7.6		7.5	1.7–13.5		13.1	9.9–14.9	
Immigrants	3.9	0.3–24.4		12.9	1.1–47.5		17.0	3.4–29.9		9.0	1.1–38.0		2.0	0.9–3.1	
Residents aged 0–17 years	14.3	9.8–27.8		17.2	8.7–23.9		16.8	12.1–23.0		16.4	10.8–22.2		17.4	14.6–19.4	
Residents aged ≥65 years	19.2	8.1–35.3		19.2	11.6–32.8		19.1	13.7–24.6		19.5	10.1–27.5		15.1	10.7–20.8	
Married residents	42.6	26.6–59.2		46.2	31.5–55.0		46.4	36.9–56.1		51.7	33.7–57.4		42.0	38.8–46.1	

Abbreviations: CARLA, Cardiovascular Disease, Living and Ageing in Halle Study; DHS, Dortmund Health Study; HNR, Heinz Nixdorf Recall Study; KORA, Cooperative Health Research in the Region of Augsburg, Survey 4; SHIP, Study of Health in Pomerania.

^a Data on context variables for CARLA were collected in 2003.

^b Data on context variables for DHS were collected in 2003.

^c Data on context variables for KORA were collected in 2000.

^d Data on context variables for HNR were collected in 2001.

^e Data on context variables for SHIP were collected in 1999 except proportion of immigrants, which was available only for 2003.

Table 3. Participant Characteristics of 5 Population-Based Studies in Germany, 1997–2006

	CARLA			DHS			KORA			HNR			SHIP		
	Mean (SD)	No.	%	Mean (SD)	No.	%	Mean (SD)	No.	%	Mean (SD)	No.	%	Mean (SD)	No.	%
Age, years	60.7 (7.9)			60.3 (8.4)			58.8 (8.5)			59.5 (7.8)			59.6 (8.4)		
Male sex		724	53.1		414	50.1		532	51.9		2,257	50.9		615	50.0
Social class															
Lower		137	10.0		144	17.4		112	10.9		569	12.8		235	19.1
Middle		862	63.2		382	46.3		525	51.2		2,410	54.4		803	65.2
Higher		365	26.8		300	36.3		389	37.9		1,453	32.8		193	15.7
Employment status															
Employed		446	32.7		303	36.7		441	43.0		1,740	39.3		421	34.2
Retired		684	50.2		355	43.0		422	41.1		1,888	42.6		638	51.8
Unemployed		188	13.8		55	6.7		78	7.6		291	6.6		165	13.4
Other ^a		46	3.4		113	13.7		85	8.3		513	11.6		7	0.6

Abbreviations: CARLA, Cardiovascular Disease, Living and Ageing in Halle Study; DHS, Dortmund Health Study; HNR, Heinz Nixdorf Recall Study; KORA, Cooperative Health Research in the Region of Augsburg, Survey 4; SD, standard deviation; SHIP, Study of Health in Pomerania.

^a Those in occupational retraining and those who choose not to work outside the home.

resided was 10,267 residents (25th percentile = 5,046; 75th percentile = 14,125).

Table 3 presents the basic characteristics of participants from the 5 study populations included in our analyses. Of the total study population of 8,879 individuals, the crude prevalence of known type 2 diabetes was 8.8% (95% confidence interval (CI): 8.2, 9.4). The prevalence ranged across regions from 6.2% in KORA (95% CI: 4.8, 7.9) to 12.7% in CARLA (95% CI: 11.0, 14.6). Across studies, the mean age ranged from 58.8 to 60.7 years, and the proportion of men ranged from 50.0% to 53.1%. Although SHIP and CARLA had more than 63.0% of subjects in the middle social class, KORA, DHS, and HNR had a large proportion of participants in the higher social class (ranging from 32.8% to 37.9%). In SHIP and CARLA, more than 50% of participants were retired and more than 13% were unemployed.

Age was strongly associated with type 2 diabetes (odds ratio (OR) per 1 year of age = 1.05, 95% CI: 1.04, 1.07; adjusted for individual variables, neighborhood unemployment rate, and proportion of immigrants; results shown in Appendix Table 1). Men had a 1.51 (95% CI: 1.28, 1.78) higher odds of type 2 diabetes than did women. Individuals belonging to the lower and middle social classes had odds ratios of 1.93 (95% CI: 1.49, 2.50) and 1.30 (95% CI: 1.06, 1.59), respectively, of type 2 diabetes compared with the highest social class. There were no significant associations between employment status and the odds of type 2 diabetes.

In Tables 4 and 5, the estimated odds ratios by study region and the estimated variance at the neighborhood and regional levels are presented. Heterogeneity in the odds of type 2 diabetes was larger on the regional level than on the neighborhood level (Table 5). When comparing one of the lowest-risk study regions with one of the highest-risk study regions, the odds ratio of type 2 diabetes increased, on average, by 23%. The average increase in the odds ratio of type 2 diabetes was 17% across neighborhoods (Table 5), as

shown in model 1. The odds of type 2 diabetes showed a southern-to-northeastern gradient. In comparison with KORA, the adjusted odds ratios were 1.98 (95% CI: 1.81, 2.14), 1.58 (95% CI: 1.40, 1.77), 1.48 (95% CI: 1.25, 1.71), and 1.17 (95% CI: 1.06, 1.29) higher in CARLA, SHIP, DHS, and HNR, respectively (Table 4), as shown in model 2. Adjustment for individual variables reduced the variation at the neighborhood level (median OR = 1.11), but the disparities on the regional level could not be explained by individual characteristics (median OR = 1.22) (Table 5), as shown in model 2. Unemployment rate at the neighborhood level explained the largest fraction of heterogeneity at the regional level (Table 5), as shown in model 3. In CARLA, the odds ratio of type 2 diabetes was still elevated at 1.29 (95% CI: 1.13, 1.45) compared with KORA (Table 4), as shown in model 3. In model 4, which was adjusted for neighborhood unemployment rate (OR = 1.05, 95% CI: 1.03, 1.06) and the proportion of immigrants (OR = 0.99, 95% CI: 0.97, 1.00), no differences existed among the study regions (Table 4). Because the proportion of immigrants was, in general, low in the eastern German study regions, we assumed that the proportion of immigrants could operate as a proxy for eastern and western Germany and might result in a clustering of eastern and western German regions. When controlling for the east-west dummy, the significant effect of the immigrant proportion (OR = 0.99, 95% CI: 0.98, 1.01) disappeared, and the effect of unemployment rate was slightly weakened (data not shown).

Table 6 shows the estimated effects of the 5 context variables (in percent and quintiles) in our analyses. Quintiles of context variables operated as predictors for disparities between neighborhoods within regions. The unemployment rate (median OR = 1.00), the proportion of immigrants (median OR = 1.08), the proportion of married residents (median OR = 1.00), and the proportion of residents aged 0–17 years (median OR = 1.00) reduced the heterogeneity

Table 4. Type 2 Diabetes by Study Regions From 3-Level Mixed Effects Logistic Regression Models With Data From 5 Population-Based Studies^a in Germany, 1997–2006

Study	Model 1 ^b		Model 2 ^c		Model 3 ^d		Model 4 ^e	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
KORA	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
SHIP	1.74	1.55, 1.92	1.58	1.40, 1.77	1.11	0.92, 1.29	0.90	0.71, 1.08
HNR	1.19	1.08, 1.30	1.17	1.06, 1.29	1.07	0.95, 1.18	0.95	0.84, 1.06
DHS	1.50	1.27, 1.73	1.48	1.25, 1.71	0.95	0.71, 1.18	0.88	0.65, 1.12
CARLA	1.99	1.83, 2.15	1.98	1.81, 2.14	1.29	1.13, 1.45	1.07	0.91, 1.23

Abbreviations: CARLA, Cardiovascular Disease, Living and Ageing in Halle Study; CI, confidence interval; DHS, Dortmund Health Study; HNR, Heinz Nixdorf Recall Study; KORA, Cooperative Health Research in the Region of Augsburg, Survey 4; OR, odds ratio; SHIP, Study of Health in Pomerania.

^a Total population, 8,879.

^b Adjusted for individual variables (age and sex).

^c Adjusted for individual variables (age, sex, social status, and employment status).

^d Adjusted for individual variables (age, sex, social status, and employment status) and neighborhood unemployment rate (%).

^e Adjusted for individual variables (age, sex, social status, and employment status), neighborhood unemployment rate (%), and proportion of immigrants (%).

between neighborhoods. Individuals residing in a neighborhood with a relative high unemployment rate showed higher odds of type 2 diabetes (in quintile 4, OR = 1.62, 95% CI:

1.25, 2.09). A high proportion of married residents was associated with a reduction of the odds ratio of type 2 diabetes to 0.75 (95% CI: 0.59, 0.95). Individuals residing in

Table 5. Model Parameters of 3-Level Mixed Effects Logistic Regression Models of Type 2 Diabetes With Data From 5 Population-Based Studies^a in Germany, 1997–2006

Model	Parameter		–2 × Loglikelihood ^b	P Value
	Area-Level Variance (SE)	Median Odds Ratio		
Model 1 ^c			5,052.66	≤0.001
Regional level	0.05 (0.04)	1.23		
Neighborhood level	0.03 (0.03)	1.17		
Model 2 ^d			5,015.09	≤0.001
Regional level	0.04 (0.04)	1.22		
Neighborhood Level	0.01 (0.03)	1.11		
Model 3 ^e			5,003.59	≤0.001
Regional level	0.00 (0.00)	1.00		
Neighborhood level	0.02 (0.03)	1.13		
Model 4 ^f			4,997.89	≤0.05
Regional level	0.00 (0.00)	1.00		
Neighborhood level	0.01 (0.03)	1.11		

Abbreviation: SE, standard error.

^a Total population was 8,879 from the following studies: Cardiovascular Disease, Living and Ageing in Halle Study; Dortmund Health Study; Heinz Nixdorf Recall Study; Cooperative Health Research in the Region of Augsburg, Survey 4; and Study of Health in Pomerania.

^b Loglikelihood ratio test for model 1 is in reference to the empty model, which is not displayed.

^c Adjusted for individual variables (age and sex).

^d Adjusted for individual variables (age, sex, social status, and employment status).

^e Adjusted for individual variables (age, sex, social status, and employment status) and neighborhood unemployment rate (%).

^f Adjusted for individual variables (age, sex, social status, and employment status), neighborhood unemployment rate (%), and proportion of immigrants (%).

Table 6. Type 2 Diabetes by Context Variables From 3-Level Mixed Effects Logistic Regression Models^a With Data From 5 Population-Based Studies^b in Germany, 1997–2006

Model Version	Unemployment Rate (Model 1)		Proportion of Immigrants (Model 2)		Proportion of Married Residents (Model 3)		Proportion of Residents Aged 0–17 Years (Model 4)		Proportion of Residents Aged ≥65 Years (Model 5)	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Version A (per 1% increase in context variable)	1.04	1.03, 1.06	1.00	0.98, 1.01	0.99	0.97, 1.00	1.03	1.00, 1.06	1.00	0.98, 1.02
Version B (per quintile)										
Quintile 1	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
Quintile 2	1.31	1.00, 1.72	1.20	0.93, 1.56	0.86	0.68, 1.09	0.91	0.72, 1.15	0.80	0.62, 1.04
Quintile 3	1.39	1.07, 1.82	1.07	0.83, 1.38	0.93	0.74, 1.15	0.96	0.76, 1.22	0.85	0.66, 1.10
Quintile 4	1.62	1.25, 2.09	1.11	0.86, 1.43	1.03	0.82, 1.30	1.08	0.86, 1.36	1.00	0.78, 1.29
Quintile 5	1.44	1.10, 1.87	1.16	0.89, 1.51	0.75	0.59, 0.95	1.21	0.97, 1.51	0.92	0.71, 1.18

Abbreviations: CI, confidence interval; OR, odds ratio.

^a Models adjusted for individual variables (age, sex, social status, and employment status).

^b Total population, 8,879 from the following studies: Cardiovascular Disease, Living and Ageing in Halle Study; Dortmund Health Study; Heinz Nixdorf Recall Study; Cooperative Health Research in the Region of Augsburg, Survey 4; and Study of Health in Pomerania.

neighborhoods with the highest proportion of residents aged 0–17 years had a nonsignificantly higher odds ratio of type 2 diabetes (OR = 1.21, 95% CI: 0.97, 1.51). The relative proportion of residents aged ≥65 years in a neighborhood did not contribute to the explanation of between-neighborhood heterogeneity (median OR = 1.13). After we controlled for unemployment rate, the statistically significant effect of a high proportion of married residents in the neighborhood was weakened and became nonsignificant (data not shown).

Continuous context variables at the neighborhood level mainly captured the variation across regions because the level and range of context variables differed significantly by region (Table 6). Unemployment rate in the neighborhood was strongly associated with the individual's odds of type 2 diabetes and explained the largest fraction of heterogeneity at the regional level (median OR = 1.00). No statistically significant association was found for the other 4 context variables. The proportion of married residents in the neighborhood marginally contributed to the explanation of heterogeneity at the neighborhood level (median OR = 1.07) and regional level (median OR = 1.20). Residing in a neighborhood with a high proportion of residents aged 0–17 years appeared to be associated with an increased odds ratio of prevalent type 2 diabetes (OR = 1.03, 95% CI: 1.00, 1.06); moreover, it contributed to the explanation of heterogeneity at the neighborhood level (median OR = 1.02). The associations between the proportion of residents aged 0–17 years and type 2 diabetes (OR = 1.01, 95% CI: 0.96, 1.05) and between the proportion of married residents and type 2 diabetes (OR = 1.00, 95% CI: 0.98, 1.01) disappeared when we adjusted for neighborhood unemployment rate (data not shown).

Although neighborhood unemployment rate was associated with an increased odds ratio of type 2 diabetes in all study regions, the magnitude of the association differed by study (data not shown). The effect of residence in a neighborhood in the highest unemployment quintile as compared

with the lowest quintile varied considerably among SHIP (OR = 1.41, 95% CI: 0.81, 2.47), HNR (OR = 1.51, 95% CI: 0.96, 2.39), DHS (OR = 5.80, 95% CI: 1.27, 26.62), CARLA (OR = 1.98, 95% CI: 0.99, 3.97), and KORA (OR = 0.65, 95% CI: 0.21, 1.98).

Individual lifestyle partially mediated the relationship between neighborhood unemployment rate and type 2 diabetes (data not shown). The lifestyle index was strongly associated with type 2 diabetes and neighborhood unemployment rate (tested via fully adjusted ordered logistic regression; OR per 1% increase in unemployment rate = 1.05, 95% CI: 1.04, 1.06). Associations between the lifestyle index and the other context variables were tested, but no relationships were found. The odds of type 2 diabetes increased with the number of unhealthy habits (for 1 unhealthy habit, OR = 1.62, 95% CI: 1.22, 2.16; for 2 unhealthy habits, OR = 2.24, 95% CI: 1.69, 2.97; for 3 unhealthy habits, OR = 3.39, 95% CI: 2.46, 4.66; and for 4 unhealthy habits, OR = 2.26, 95% CI: 0.98, 5.22). After introducing the lifestyle index into the model, a reduction in the odds ratios of type 2 diabetes was observed across all quintiles of unemployment rate (e.g., in quintile 4, from OR = 1.65, 95% CI: 1.28, 2.14 to OR = 1.56, 95% CI: 1.20, 2.02), but the association between unemployment rate and type 2 diabetes remained statistically significant.

DISCUSSION

This study evaluated the association between the residential environment and the odds of type 2 diabetes by using data from 5 regional studies in Germany. We considered the individual, neighborhood, and regional levels in simultaneous analyses by using multilevel mixed effects logistic regression models. Analyses were intended to assess whether context variables explained the heterogeneity in type 2

diabetes at the neighborhood and regional levels independent of individual variables.

Our study had 3 main results. First, we showed that regional disparities in the prevalence of type 2 diabetes remained after adjustment for individual characteristics. Substantial differences were noted between neighborhoods within study regions. The odds of type 2 diabetes were highest in the east and northeast of Germany and decreased to the southwest. The heterogeneity in the odds of type 2 diabetes was larger at the regional level than at the neighborhood level. Second, the diverging levels of unemployment in neighborhoods between regions and within regions themselves were identified as 1 source of spatial disparities of type 2 diabetes prevalence. Neighborhood unemployment rate explained a large fraction of between-neighborhood and between-region differences in the prevalence of type 2 diabetes. Third, health-related behavior was identified as a potential mediator in the association between neighborhood unemployment rate and type 2 diabetes.

Population-based data on the prevalence of type 2 diabetes at the neighborhood and regional levels are still rare. The focus of this study, the health outcome of type 2 diabetes, has received only limited attention in research concerning the residential environment as a source of increased vulnerability to type 2 diabetes. One of the main strengths of our study, aside from the assessment of neighborhood and regional disparities in the odds of type 2 diabetes, is the identification of potential explanatory variables at the neighborhood level. The application of a multilevel approach enabled us to disentangle the contextual effects at different levels from the effects of the population composition.

Unemployment rate as a proxy for neighborhoods' and regions' economic status operates as a strong predictor of health outcomes (25, 27, 29). Our results support the neo-materialistic theory that concerns the influence of socio-economic inequality, the long-term impact of poverty, and limited neighborhood resources on health. The theory states that individuals residing in deprived neighborhoods have poor access to collective social and material resources and infrastructure ("collective resources model"), which constitutes an important determinant of health inequalities (7).

Little is known about the underlying mechanisms in the relationship between the residential environment and the development of type 2 diabetes (38). Researchers have identified 2 interrelated mechanisms as potential mediators: the adoption and maintenance of health-related behavior and psychosocial factors such as chronic stress (11). We found evidence that an individual's lifestyle partly mediates the association between neighborhood unemployment rate and type 2 diabetes. Research on physical activity and the influence of the residential environment (e.g., safety, access to sports facilities) already gives insight into potential mechanisms operating in the relationship between residential environment and type 2 diabetes (39).

Our study had a number of limitations. The investigated outcome was based on self-reported physicians' diagnoses of type 2 diabetes. Studies on the quality of self-reported chronic conditions note the high accuracy of self-reports of diabetes (40). All considered studies were affected by nonresponse, and the differences in response rates (56%–96%)

may have biased our results. Our findings were based on cross-sectional analyses. No conclusions on causal inferences should be made. We could not gain any insights into the stability of the mediating effects over time and whether there is evidence for causality.

The definition of neighborhoods relied on administrative boundaries, which might not reflect the close living environment of the individuals residing there, and their definitions differed among the regions under study. Among study regions, the neighborhoods varied in geographic size and number of inhabitants. The varying spatial distribution of type 2 diabetes prevalence might be the result of a selection of diseased individuals and individuals who are vulnerable to disease into deprived neighborhoods and not a direct influence of deprivation on the development of disease (41).

In conclusion, our study is one of the first to show regional disparities in the odds of type 2 diabetes in Germany and to identify a strong association between neighborhood factors like unemployment rate and type 2 diabetes, independent of established individual risk factors for diabetes. We were able to provide evidence for a mediating role of health-related behaviors on the path from neighborhood deprivation to increased odds of type 2 diabetes. Further analyses of longitudinal data are needed to confirm the causal associations.

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Appendix Table 1. Type 2 Diabetes by Individual-Level Variables, Adjusted for Neighborhood Unemployment Rate and Proportion of Immigrants in 3-Level Mixed Effects Logistic Regression Models With Data From 5 Population-Based Studies^a in Germany, 1997–2006

Individual-Level Variables	OR	95% CI
Age ^b	1.05	1.04, 1.07
Sex		
Female	1.00	Referent
Male	1.51	1.28, 1.78
Social class		
Higher social class	1.00	Referent
Middle social class	1.30	1.06, 1.59
Lower social class	1.93	1.49, 2.50
Employment status		
Employed	1.00	Referent
Retired	1.24	0.95, 1.62
Unemployed	1.12	0.81, 1.54
Other ^c	1.15	0.81, 1.65

Abbreviations: CI, confidence interval; OR, odds ratio.

^a Total population, 8,879 from the following studies: Cardiovascular Disease, Living and Ageing in Halle Study; Dortmund Health Study; Heinz Nixdorf Recall Study; Cooperative Health Research in the Region of Augsburg, Survey 4; and Study of Health in Pomerania.

^b Odds ratio per 1 year of age with age measured as a continuous variable.

^c Those in occupational retraining and those who choose not to work outside the home.