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The impact of regional deprivation and individual socio-economic status on the prevalence of Type 2 diabetes in Germany. A pooled analysis of five population-based studies

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Abstract

Aim Our objective was to test the hypothesis that the prevalence of Type 2 diabetes increases with increasing regional deprivation even after controlling for individual socio-economic status.

Methods We pooled cross-sectional data from five German population-based studies. The data set contained information on n = 11 688 study participants (men 50.1%) aged 45–74 years, of whom 1008 people had prevalent Type 2 diabetes (men 56.2%). Logistic multilevel regression was performed to estimate odds ratios (OR) and 95% confidence intervals (CI) for diabetes prevalence. We controlled for sex, age and lifestyle risk factors, individual socio-economic status and regional deprivation, based on a new small-area deprivation measure, the German Index of Multiple Deprivation.

Results Adjusted for sex, age, body mass index (BMI), physical activity, smoking status and alcohol consumption, the prevalence of Type 2 diabetes showed a stepwise increase in risk with increasing area deprivation [OR 1.88 (95% CI 1.16–3.04) in quintile 4 and OR 2.14 (95% CI 1.29–3.55) in quintile 5 compared with the least deprived quintile 1], even after controlling for individual socio-economic status. Focusing on individual socio-economic status alone, the risk of having diabetes was significantly higher for low compared with medium or high educational level [OR 1.46 (95% CI 1.24–1.71)] and for the lowest compared with the highest income group [OR 1.53 (95% CI 1.18–1.99)].

Conclusion Regional deprivation plays a significant part in the explanation of diabetes prevalence in Germany independently of individual socio-economic status. The results of the present study could help to target public health measures in deprived regions.

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Introduction

There is strong evidence that socio-economic status (SES) plays an important role in the prevalence of Type 2 diabetes [1]. Generally, the impact of SES on health can be evaluated using either individual SES characteristics such as income or educational level [2, 3] or area-based socio-economic measures in the form of deprivation indices. These regional indices are often used as a proxy for individual SES [4].

A number of studies indicate that the prevalence of Type 2 diabetes is higher in deprived areas than in more affluent areas [5,6]. However, in order to demonstrate an independent association between area deprivation and health, it is essential to control for individual SES, but these

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analyses are still scarce [7]. Multilevel modelling is a widely used tool to disentangle the influences of individual and regional measures of SES on health [8,9]. However, there are only a few examples of studies that have used this approach to examine the social and regional distribution of Type 2 diabetes prevalence outside English-speaking countries [10].

In Germany, there are significant regional differences in the prevalence of Type 2 diabetes. The highest age-standardized prevalence has been found in the east (12.0%) and the lowest in the south of Germany (5.8%) [11]. Using pooled data from five German population-based studies, our objective was to test the hypothesis that the prevalence of Type 2 diabetes increases with increasing regional deprivation even after controlling for individual SES. The analyses are based on a new small-area deprivation measure, the German Index of Multiple Deprivation (GIMD), derived from a method developed in the UK [12] and adapted for municipalities in Germany [13,14].

Methods

Cross-sectional data from five regional population-based studies were available within the Diabetes Collaborative Research of Epidemiologic Studies (DIAB-CORE). The five studies have been conducted across Germany, one in the north-east [the Study of Health in Pomerania (SHIP)], one in the east [the Cardiovascular Disease, Living and Ageing in Halle Study (CARLA)], two in the west [the Heinz Nixdorf Recall Study (HNR) in the cities of Essen, Bochum and Mülheim in the Ruhr Area, and the Dortmund Health Study (DHS)] and one in the south [Cooperative Health Research in the Region of Augsburg Survey 4 (KORA S4)]. All studies are comparable with regard to study design (population-based sampling), sampling methods (two-stage cluster sampling or stratified random sampling) and response rates (between 56% and 69%), and all were approved by ethics committees. In each of the geographically defined study areas, samples of the population were randomly drawn from mandatory population registers, stratified by age and sex. More detailed information on these studies conducted between 1997 and 2006 and the pooling of the data has been described previously [11,15–20].

The analyses were restricted to participants aged between 45 and 74 years. The pooled data set contained information on $n = 11\,688$ study participants (men 50.1%), of whom 1008 people had prevalent Type 2 diabetes (men 56.2%).

Individual-level data were available for Type 2 diabetes status, sex, age (45–54, 55–64 and 65–74 years), income, educational level, BMI, physical activity, smoking status and alcohol consumption. Type 2 diabetes was defined by self-reported physician-diagnosed diabetes or self-reported diabetes treatment (dietary, oral or insulin treatment). In order to focus on Type 2 diabetes, only those with age at diagnosis of diabetes of > 30 years were included.

Information on monthly net household income as well as on household size was obtained from interviews. As the ages of household members were not available consistently across all studies, it was not possible to calculate the equivalent income according to the OECD equivalence scale. That is why the equivalent income was calculated according to the Luxembourg Income Study (income/household size$^{0.36}$) [21]. Pooling of income data was conducted by a regional approach, calculating the median income for each of the five study centres separately. This approach allowed us to take into account overall income differences between the regions. For each study, we differentiated four income groups (< 60% of the study-specific median income, $\geq$ 60% up to 100%, > 100% up to $\leq$ 150% and > 150%) and pooled these groups across the five studies.

In all studies, the participants were asked for their highest level of school qualification obtained. We classified educational level as a dichotomous variable, contrasting low with medium or high level. According to the German school system, low educational level includes participants with up to 9 years of schooling. Medium educational level is equivalent to 10 years of schooling and high educational level to 12 or 13 years of schooling, which is required to enter a university.

Occupational social class could not be used to define individual SES; occupation has been assessed in very broad terms that do not represent a clear socio-economic hierarchy.

In order to control for possible confounding by different lifestyle risk factors, we included BMI (three categories: < 25 kg/m^2, 25 up to < 30 kg/m^2 and $\geq$ 30 kg/m^2), physical activity (two categories: $\geq$ 1 h/week and < 1 h/week), smoking status (three categories: never smoker, ex-smoker and current smoker) and alcohol consumption (two categories: low-risk and high-risk consumption, based on sex-specific thresholds according to World Health Organization (WHO) recommendations (20 g/day in women, 40 g/day in men) in our analyses [22]. Covariates concerning individual SES and health behaviour were assessed in interviews, whereas weight and height were measured by trained personnel. Standardized coding of variables and a number of plausibility checks ensured a high degree of comparability between the five data sets [11].

Regional deprivation was assessed by a small area-based measure at the municipality level that was assigned to each study participant. This German Index of Multiple Deprivation has been established based on the method used in the UK to create the Indices of Multiple Deprivation (IMD) [12]. Adapted to the German context, previous publications focusing on the State of Bavaria demonstrated strong associations between regional deprivation, on the one hand, and overall mortality and cancer incidence and mortality on the other [13,14]. For the present study, we calculated the German Index of Multiple Deprivation scores for 9620 municipalities covering the whole of Germany. The Index includes eight indicators on demographic, socio-economic and environmental characteristics related to seven different domains of deprivation (i.e. income, employment, education, municipal revenue, social capital, environment and security). We assigned the municipalities to deprivation quintiles, with quintile 1 including the least deprived and quintile 5 the most deprived areas. More details on the German adaptation of the Indices of Multiple Deprivation have been published elsewhere [13,14]. Municipalities are the lowest level of administrative division in Germany and cover a wide range of population size, including small rural municipalities with less than 100 inhabitants, up to cities with more than one million inhabitants, such as Munich or Berlin. For the SHIP study, we had to use clusters of municipalities for reasons of data protection. Overall, 30 spatial units (municipalities or cluster of municipalities) were included in our analyses. The cities of Essen (HNR) and Dortmund (DHS) had the highest population size, both with approximately 580 000 inhabitants; the municipality of Eurasburg in the KORA study was the smallest spatial unit with approximately 1700 inhabitants.

We carried out univariate and bivariate analyses and calculated crude odds ratios (OR) with their 95% confidence intervals (CI). Then we performed logistic multilevel regression models, fitting two-level binomial logit-link models (level 1: individuals; level 2: municipalities) with random intercept. In four subsequent models, OR with their 95% CI were calculated to test for associations between municipality deprivation and Type 2 diabetes prevalence, controlling for different potential confounders at the individual level (age, sex, BMI, physical activity, smoking status, alcohol consumption, educational level and income).

We report the area-level variances (V_A) with their standard errors. In order to obtain a more interpretable measure for quantifying the relevance of area-level variation, we also calculated the median odds ratios (MOR). The median odds ratio translates the area-level variance to the odds ratio scale, enabling a more intuitive comparison with the effect of individual level covariates. It is defined as the median of odds ratios between the area at higher risk and the area at lower risk, when considering two individuals with the same characteristics randomly chosen from two different areas. The MOR can be calculated as a simple function of the area-level variance V_A [23]: $\text{MOR} = \exp[\sqrt{(2 \times V_A)} \times 0.6745]$.

We also tested for a linear trend between age-adjusted diabetes prevalence per municipality and its corresponding GIMD score. All analyses were performed as available case analysis, using the software SAS 9.2 (SAS Institute Inc., Cary, NC, USA). Logistic multilevel models were estimated with the SAS procedure GLIMMIX, using a residual pseudo-likelihood estimation method (RSPL).

Results

Table 1 shows the distribution of individual and area-based characteristics, as well as the results of the Cochran–Armitage test for trend. From a total of 11 688 study participants, 8.6% ($n = 1008$) had Type 2 diabetes. The crude Type 2 diabetes prevalence is highest in the east of Germany (CARLA) with 12.6% and lowest in the south (KORA S4) with 6.0%.

Table 2 shows the results of the multilevel analyses (crude odds ratios and four adjusted models). Models 1 and 3 demonstrate the association between individual SES (educational level, income) and the prevalence of Type 2 diabetes, whereas models 2 and 4 show the association between diabetes and area deprivation controlled for individual SES. The models clearly show that the socio-economic status of municipalities is strongly associated with the prevalence of Type 2 diabetes, and that this association is quite independent of individual SES. Regarding the area-level variance and the MOR in Table 2, the variance between municipalities decreases when adding the deprivation quintiles to the respective models.

The prevalence of Type 2 diabetes is clearly higher for men than for women [OR 1.30 (95% CI 1.14–1.48)], for the oldest age group (65–74 years) compared with the youngest age group (45–54 years) [OR 3.61 (95% CI 2.99–4.36)], for the highest BMI group ($\text{BMI} \geq 30\ \text{kg/m}^2$) compared with the lowest ($\text{BMI} < 25\ \text{kg/m}^2$) [OR 4.81 (95% CI 3.86–5.99)] and for study participants with less than 1 h of physical activity per week [OR 1.92 (95% CI 1.67–2.21)]. Compared with never smokers, Type 2 diabetes is less prevalent in current smokers [OR 0.69 (95% CI 0.57–0.83)] than in ex-smokers [OR 1.22 (95% CI 1.06–1.41)] and in study participants with a high level of alcohol consumption [OR 0.62 (95% CI 0.47–0.81)]. The prevalence of Type 2 diabetes is higher for those with low compared with medium or high educational level [OR 1.99 (95% CI 1.71–2.32)] and for those in the lowest income group (< 60%) compared with the highest income group (> 150%) [OR 2.08 (95% CI 1.63–2.65)]. The crude Type 2 diabetes prevalence shows a stepwise increase with increasing area deprivation [OR 2.43 (95% CI 1.47–4.04)] in the most deprived quintile 5 compared with the least deprived quintile 1. However, the increased risk of area deprivation is only significant in quintiles 4 and 5, compared with the least deprived quintile 1.

Stratified analyses by sex show that the effects of individual SES and of regional deprivation on Type 2 diabetes prevalence are both slightly more pronounced among women than among men. For low educational level, the OR for women is 1.57 (95% CI 1.20–2.07) and for men 1.36 (95% CI 1.11–1.67). For living in the region with the greatest deprivation (i.e. quintile 5, controlling for educational level), the OR for women is 2.16 (95% CI 1.08–4.35) and for men 1.99 (95% CI 1.10–3.59). For low equivalent income, the OR for women is 1.60 (95% CI 1.04–2.47) and for men 1.47 (95% CI 1.04–2.08). For living in the region with the greatest deprivation (i.e. quintile 5, controlling for equivalent income) the OR is

Table 1 Distribution of individual-level and area-level characteristics in five German population-based studies

	CARLA	DHS	HNR	KORA S4	SHIP	Total	Prevalence of T2D*
Municipalities (*n*)	1	1	3	17	8	30	
Study participants (*n*)	1382	883	4734	2442	2247	11 688	
Prevalence of Type 2 diabetes (%)	12.6	9.9	7.4	6.0	11.2	8.6	
Independent variables (%)							
Sex							
Women	47.1	50.6	50.3	50.3	50.2	49.9	7.6
Men	52.9	49.4	49.8	49.8	49.8	50.1	9.7
Age (years)							
45–54	29.8	31.3	31.2	35.3	32.9	32.3	4.1
55–64	36.7	37.2	39.6	34.7	37.3	37.6	8.6
65–74	33.5	31.6	29.1	29.9	29.8	30.1	13.5†
BMI (kg/m^2)							
< 25	25.5	25.9	26.5	22.4	23.1	24.8	3.5
25 to < 30	42.4	42.1	46.0	47.8	44.6	45.4	7.4
≥ 30	32.1	32.1	27.4	29.7	32.3	29.8	14.8†
Physical activity							
≥ 1 h/week	29.7	46.0	54.0	60.9	35.8	48.4	5.8
< 1 h/week	70.3	54.0	46.0	39.2	64.2	51.6	11.2
Smoking status							
Never smoker	44.9	44.9	46.1	45.4	51.3	46.7	8.7
Ex-smoker	33.2	34.2	32.8	34.0	27.2	32.1	10.2
Current smoker	21.9	20.9	21.1	20.6	21.5	21.2	6.2‡
Alcohol consumption							
Low risk	91.1	89.9	94.7	82.6	90.3	90.5	8.9
High risk	8.9	10.1	5.3	17.4	9.7	9.5	5.6
Educational level							
High/medium level	44.2	36.5	38.2	34.4	27.4	35.9	5.5
Low level	55.8	63.5	61.8	65.6	72.6	64.1	10.4
Equivalent income (as% of median income)							
> 150 (= affluent)	18.3	22.6	21.3	24.4	16.5	20.7	5.7
> 100 to ≤ 150	21.5	27.9	23.3	22.2	34.7	25.4	7.9
≥ 60 to ≤ 100	50.7	36.6	41.3	43.7	34.0	41.2	9.8
< 60 (= poor)	9.5	13.0	14.1	9.7	14.8	12.7	11.5†
GIMD quintiles (Q)							
Q1 (= least deprived)	—	—	—	25.2	—	5.3	4.7
Q2	—	—	—	16.3	—	3.4	7.5
Q3	—	—	—	13.8	6.4	4.1	7.5
Q4	100.0	100.0	65.7	44.7	33.7	61.8	8.5
Q5 (= most deprived)	—	—	34.3	—	59.9	25.4	10.0†

*Prevalence of Type 2 diabetes (%).
P for trend (†*P*< 0.0001; ‡*P* < 0.01).
Missing values: BMI *n* = 41; physical activity *n* = 10; smoking status *n* = 8; alcohol consumption *n* = 128; educational level *n* = 39; equivalent income *n* = 668; no missing values in other variables.

2.20 (95% CI 1.04–4.68) for women and 2.14 (95% CI 1.17–3.92) for men.

The distribution of the German Index of Multiple Deprivation score for the whole of Germany is characterized as follows: median 19.67; interquartile range 14.31. The bubble plot in Fig. 1 demonstrates that the age-adjusted prevalence of Type 2 diabetes increases with increasing area deprivation. The municipalities in our study differ markedly in population size and are not equally distributed across the GIMD quintiles. The linear trend between Type 2 diabetes prevalence and the GIMD score of the municipalities in Fig. 1 is clearly positive and highly statistically significant with $P < 0.001$.

Discussion

Our objective was to analyse whether regional differences in the prevalence of Type 2 diabetes are associated with the deprivation status of the place of residence, independently of individual socio-economic factors such as education or income. Our findings suggest that the socio-economic status of municipalities plays a significant part in the explanation of diabetes prevalence. Not only individual SES but also regional SES seems to be associated with individual health outcomes. To our knowledge, this study is the first to assess the prevalence of Type 2 diabetes at a municipality level regarding both individual and regional social factors using

Table 2 Models of associations between Type 2 diabetes risk, individual socio-economic status and area deprivation

	Crude odds ratio† Odds ratio (95% CI)	Model 1 Odds ratio (95% CI) (*n* = 11 482)	Model 2 Odds ratio (95% CI) (*n* = 11 482)	Model 3 Odds ratio (95% CI) (*n* = 10 879)	Model 4 Odds ratio (95% CI) (*n* = 10 879)
Sex (*women)					
Men	**1.30** (1.14–1.48)	**1.30** (1.12–1.51)	**1.30** (1.12–1.51)	**1.28** (1.10–1.50)	**1.28** (1.10–1.49)
Age (*45–54 years)					
55–64 years	**2.18** (1.80–2.65)	**1.82** (1.49–2.22)	**1.81** (1.48–2.21)	**1.95** (1.60–2.39)	**1.95** (1.59–2.39)
65–74 years	**3.61** (2.99–4.36)	**2.72** (2.23–3.31)	**2.72** (2.23–3.31)	**2.91** (2.37–3.56)	**2.91** (2.38–3.57)
BMI (*< 25 kg/m^2)					
25 to < 30 kg/m^2	**2.22** (1.78–2.78)	**1.85** (1.47–2.34)	**1.86** (1.48–2.35)	**1.94** (1.53–2.46)	**1.95** (1.53–2.47)
$\geq$ 30 kg/m^2	**4.81** (3.86–5.99)	**3.83** (3.04–4.81)	**3.85** (3.06–4.83)	**4.00** (3.16–5.06)	**4.01** (3.17–5.08)
Physical activity (* $\geq$ 1 h/week)					
< 1 h/week	**1.92** (1.67–2.21)	**1.63** (1.41–1.88)	**1.60** (1.39–1.85)	**1.62** (1.39–1.87)	**1.59** (1.37–1.85)
Smoking status (*never smoker)					
Ex-smoker	**1.22** (1.06–1.41)	1.11 (0.94–1.30)	1.11 (0.94–1.30)	1.11 (0.94–1.30)	1.11 (0.94–1.31)
Current smoker	**0.69** (0.57–0.83)	0.86 (0.70–1.06)	0.86 (0.70–1.05)	0.91 (0.74–1.13)	0.90 (0.73–1.12)
Alcohol consumption (*low risk)					
High risk	**0.62** (0.47–0.81)	**0.68** (0.52–0.90)	**0.70** (0.53–0.92)	**0.69** (0.52–0.91)	**0.71** (0.53–0.93)
Educational level (*high/medium level)					
Low level	**1.99** (1.71–2.32)	**1.46** (1.24–1.71)	**1.46** (1.25–1.72)	—	—
Equivalent income (*> 150% of median income = affluent)					
> 100 to $\leq$ 150	**1.35** (1.08–1.69)	—	—	1.11 (0.88–1.41)	1.10 (0.87–1.39)
$\geq$ 60 to $\leq$ 100	**1.75** (1.43–2.14)	—	—	1.22 (0.98–1.51)	1.21 (0.98–1.50)
< 60 (= poor)	**2.08** (1.63–2.65)	—	—	**1.53** (1.18–1.99)	**1.53** (1.18–1.98)
GIMD (*Q1 = least deprived)					
Q2	1.65 (0.89–3.06)	—	1.43 (0.78–2.62)	—	1.53 (0.82–2.87)
Q3	1.57 (0.86–2.86)	—	1.45 (0.81–2.59)	—	1.53 (0.83–2.81)
Q4	**1.97** (1.22–3.20)	—	**1.84** (1.16–2.90)	—	**1.88** (1.16–3.04)
Q5 (= most deprived)	**2.43** (1.47–4.04)	—	**2.04** (1.26–3.30)	—	**2.14** (1.29–3.55)
Area-level variance V_A (SE)	—	0.060 (0.033)	0.050 (0.029)	0.069 (0.040)	0.059 (0.035)
Median odds ratio		1.26	1.24	1.29	1.26

*Comparison group; bold type indicates significant.
†Crude odds ratios: unadjusted odds ratios of all covariates.
SE: standard error.
Model 1: individual SES (educational level), adjusted for sex, age, BMI and lifestyle covariates.
Model 2: individual SES (educational level) + regional deprivation, adjusted for sex, age, BMI and lifestyle covariates.
Model 3: individual SES (equivalent income), adjusted for sex, age, BMI and lifestyle covariates.
Model 4: individual SES (equivalent income) + regional deprivation, adjusted for sex, age, BMI and lifestyle covariates.

multilevel analysis and a small area-based deprivation index for Germany.

As shown previously, Type 2 diabetes showed a strong association with age, sex, BMI and physical activity, but not with smoking status. The inverse relationship of alcohol consumption and diabetes risk has already been described elsewhere [24].

Our main analyses showed two principal findings: first, we were able to confirm a significant association between individual SES, measured by educational level and equivalent income, and the prevalence of Type 2 diabetes. Second, there is a significant association between diabetes prevalence and regional deprivation at the municipality level; increased risks are seen in the very deprived areas of deprivation quintiles 4 and 5 compared with the least deprived quintile 1. In all our models, these associations were independent of major potential risk factors such as sex, age, BMI, physical activity, smoking status and alcohol consumption.

Our findings are in good agreement with results reported from other countries. Following Smith [25], education could have a stronger impact on health than individual financial resources. People with a higher educational level show more competence in dealing with health and disease, and thus educational level shows a positive association with time to onset of diabetes [26]. Also, having a higher educational level generally leads to better health literacy, i.e. a better understanding of healthcare instructions such as glycaemic control in people who have already developed diabetes [27].

The association between equivalent income and the prevalence of Type 2 diabetes has already been reported in other studies [3]. There are several potential pathways concerning the effect of income: first, low income may result in limited access to an adequate food supply. Food insecurity (i.e. the availability of food) is a potential risk factor for diabetes, as already shown by data from the National Health Examination and Nutrition Examination Survey (NHANES)

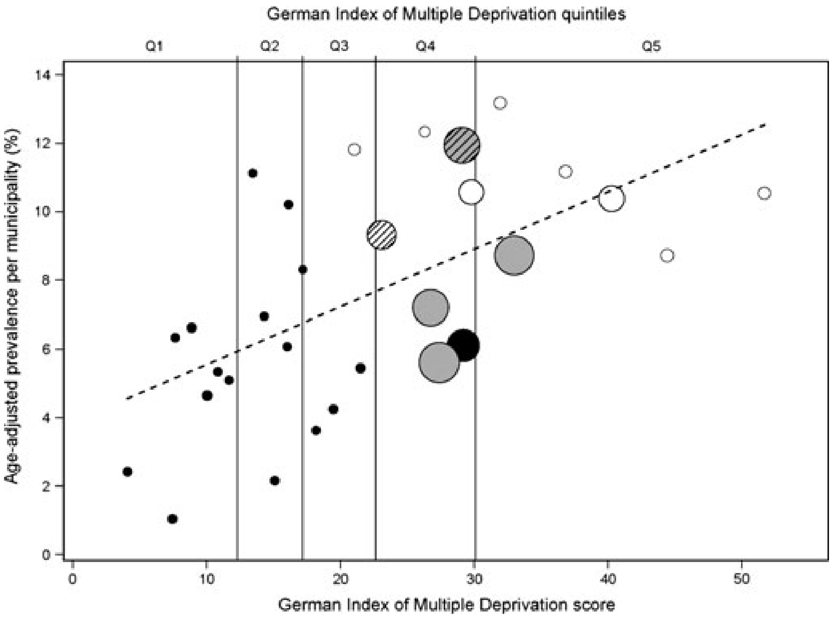

FIGURE 1 Bubble plot* of the association between age-adjusted† Type 2 diabetes mellitus prevalence per municipality and area deprivation (German Index of Multiple Deprivation score and quintiles; Q1 = least deprived, Q5 = most deprived). *Size of bubbles proportional to the number of participants in the municipalities. †Standardized to the German population (31 December 2007). KORA S4 (●), CARLA (▨), HNR (◍), DHS (▨), SHIP (○).

[28]. Furthermore, the quality of diet plays an important role in diabetes risk. There is some evidence that higher cereal fibre and magnesium intake as well as fruit and vegetable intake could reduce the risk of Type 2 diabetes [29,30]. Also, low socio-economic status groups are more likely to consume low-quality food [31]. Second, sedentary behaviour increases the risk of developing diabetes and physical activity is an effective means of reducing this risk [32]. However, financial constraints could be a major barrier for lower income people being willing to participate in sports activities, which might decrease their risk of developing diabetes [33]. Third, compared with higher income groups, lower income groups generally live in places with lower environmental quality [34] and higher exposure to air pollution. Some studies have indicated an association between diabetes prevalence and air pollution [35], which could be partially explained by subclinical inflammation [36].

Beyond individual SES, regional socio-economic influences can also have an impact on health. We found a clear positive association between regional deprivation and diabetes prevalence even after controlling for individual characteristics. Thus, our results point in the same direction as findings from other studies [10]. Potential overadjustment from using both individual and aggregate socio-economic status has been discussed, but seems rather improbable in our data because there was no significant change in the strengths of associations when modelling both SES levels [7].

There is an ongoing discussion about the independence between the effect at the individual vs. the regional level. In our analyses, adjustment for individual-level factors seems to have little influence on the magnitude of the regional deprivation effect, i.e. both effects seem to be quite independent. There are several potential explanations for this result. Individual SES and regional deprivation may act through different pathways [37]. Whereas individual SES may have a direct influence on health behaviour, the influence of regional deprivation may interact through specific mechanisms of regional norms and attitudes and by collective resources [38]. Area-specific health resources could comprise characteristics such as local economic opportunities, healthcare services, availability and accessibility of healthy food and of facilities for physical activity. In a number of studies on regional deprivation and health, it has been shown that a lack of potential resources may lead to negative health outcomes. Psycho-social factors such as chronic stress caused by lack of security or by environmental exposures [39] and urban/rural differences in the utilization of the healthcare system [10] may all be part of the mechanism linking regional deprivation and individual health.

Associations have also been found between low socio-economic status in childhood and increased risk of Type 2 diabetes and obesity in later life [40]. Area deprivation could contribute to this association in a number of ways. If a low SES family lives in a deprived region, the detrimental effects of the region could increase the detrimental effects of individual SES. If a low SES family lives in a more privileged region, however, there would be more chance of overcoming the link between childhood SES and diabetes in adulthood. That is why we would recommend including regional deprivation variables in life course studies that focus on the association between childhood SES and diabetes.

However, there is still little knowledge regarding which aspects of regional deprivation may have the strongest and most direct impact on diabetes. Most probably, there will not be one single area characteristic that needs to be changed in order to improve the health status of the inhabitants of the region [41]. Disentangling area effects and finding the most promising starting points for interventions will be a major task.

Some limitations of our study have to be taken into account. First, the cross-sectional design of the data set does not allow any causal interpretation of our findings. Second, Type 2 diabetes was defined by self-reported physician-diagnosed diabetes, which could lead to potential problems of misclassification [15]. However, other studies indicate that self-reported diabetes leads to very similar associations between social status and diabetes prevalence as, for example, the examination of fasting blood glucose levels [42]. Third, our analyses are based on municipalities as spatial units for assessing regional deprivation. Unlike the UK [12], municipalities are the smallest spatial units for which official statistics are available in Germany; however, these administrative units vary considerably in area and population size. Consequently, the classification of individuals by their regional deprivation status may be more sensitive in smaller municipalities than in bigger cities. There may be some differential misclassification attributable to the different number of municipalities across the studies. The probability of assigning people with diabetes to a deprivation quintile in a study with only one municipality is certainly different from a study with 17 municipalities. However, it is difficult to assess the direction and magnitude of this potential source of bias. Also, the municipalities in studies with more than one centre are not equally spread across the possible range of deprivation quintiles. This may explain why there does not seem to be a strong relationship between deprivation and diabetes prevalence within these studies (see Fig. 1). Following Streiner and Norman [45], it can be demonstrated that the association between two measures decreases if the range of scores is restricted. Restricting the analysis to a single study would mean to apply the German Index of Multiple Deprivation to a less heterogeneous group than the one it was designed for. The potential for non-response bias must be considered as well. People with poor health are often underrepresented in epidemiological studies. Using a KORA survey as an example, low educational level and diabetes have both been associated with non-response [43]. Again, it is difficult to assess how this potential source of bias might have influenced our results. Selective study participation could also be subject to a potential bias caused by local deprivation status [44]. Another limitation of our analysis is that we could not adjust for dietary variables and had no information on individual chronic stress and depression.

There are some important strengths in this study. It is based on a large data set, comprising individual data from five highly comparable population-based studies conducted across Germany. This is a unique resource for studying the regional differences in Type 2 diabetes. As far as we know, there is no comparable data set from other countries. Other studies use extensive databases, but information on individual socio-economic status is often missing and regional deprivation is included as a proxy for individual SES [6]. Including both individual SES and an area-based deprivation measure, we were able to quantify the impact of small-area deprivation on the prevalence of Type 2 diabetes in Germany. A few studies looking at regional deprivation also adjusted for individual SES, but their results were only valid for women [7] or used less specific measures of individual socio-economic status than our study [10].

In conclusion, both individual SES and regional deprivation were independently associated with the prevalence of Type 2 diabetes. By identifying deprived regions in Germany and demonstrating the impact of regional deprivation on Type 2 diabetes, our findings could be of some public health relevance. It could be concluded that interventions aimed at preventing Type 2 diabetes should not just focus on individuals with low socio-economic status, but also on deprived regions. Population-based prevention initiatives are important in their own right. They can address risk factors and resources that jointly affect many people and are beyond their immediate individual responsibility, such as the availability of facilities for physical activity or the provision of high-quality medical services. Also, there is increasing evidence that community-based interventions can result in improved knowledge of and access to fruit and vegetables [46]. These initiatives could thus have a long-term effect on improving the health of the total population living in a region.

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Competing interests

None declared.

References

1 Brown AF, Ettner SL, Piette J, Weinberger M, Gregg E, Shapiro MF *et al.* Socioeconomic position and health among persons with diabetes mellitus: a conceptual framework and review of the literature. *Epidemiol Rev* 2004; **26**: 63–77.

2 Espelt A, Borrell C, Roskam AJ, Rodriguez-Sanz M, Stirbu I, Dalmau-Bueno A *et al.* Socioeconomic inequalities in diabetes mellitus across Europe at the beginning of the 21st century. *Diabetologia* 2008; **51**: 1971–1979.

3 Dinca-Panaitescu S, Dinca-Panaitescu M, Bryant T, Daiski I, Pilkington B, Raphael D. Diabetes prevalence and income: results of the Canadian Community Health Survey. *Health Policy* 2011; **99**: 116–123.

4 Evans JMM, Newton RW, Ruta DA, MacDonald TM, Morris AD. Socio-economic status, obesity and prevalence of Type 1 and Type 2 diabetes mellitus. *Diabet Med* 2000; **17**: 478–480.

5 Connolly V, Unwin N, Sherriff P, Bilous R, Kelly W. Diabetes prevalence and socioeconomic status: a population based study showing increased prevalence of type 2 diabetes mellitus in deprived areas. *J Epidemiol Community Health* 2000; **54**: 173–177.

6 Walker JJ, Livingstone SJ, Colhoun HM, Lindsay RS, McKnight JA, Morris AD *et al.* Effect of socioeconomic status on mortality among people with type 2 diabetes: a study from the Scottish Diabetes Research Network Epidemiology Group. *Diabetes Care* 2011; **34**: 1127–1132.

7 Andersen AF, Carson C, Watt HC, Lawlor DA, Avlund K, Ebrahim S. Life-course socio-economic position, area deprivation and Type 2 diabetes: findings from the British Women's Heart and Health Study. *Diabet Med* 2008; **25**: 1462–1468.

8 Adams RJ, Howard N, Tucker G, Appleton S, Taylor AW, Chittleborough C *et al.* Effects of area deprivation on health risks and outcomes: a multilevel, cross-sectional, Australian population study. *Int J Public Health* 2009; **54**: 183–192.

9 Leyland AH. Socioeconomic gradients in the prevalence of cardiovascular disease in Scotland: the roles of composition and context. *J Epidemiol Community Health* 2005; **59**: 799–803.

10 Bocquier A, Cortaredona S, Nauleau S, Jardin M, Verger P. Prevalence of treated diabetes: geographical variations at the small-area level and their association with area-level characteristics. A multilevel analysis in southeastern France. *Diabetes Metab* 2011; **37**: 39–46.

11 Schipf S, Werner A, Tamayo T, Holle R, Schunk M, Maier W *et al.* Regional differences in the prevalence of known Type 2 diabetes mellitus in 45–74 years old individuals: results from six population-based studies in Germany (DIAB-CORE Consortium). *Diabet Med* 2012; **29**: e88–95. [Epub ahead of print].

12 Noble M, Wright G, Smith G, Dibben C. Measuring multiple deprivation at the small-area level. *Environ Plan A* 2006; **38**: 169–185.

13 Maier W, Fairburn J, Mielck A. Regionale Deprivation und Mortalität in Bayern. Entwicklung eines 'Index Multipler Deprivation' auf Gemeindeebene. [Regional Deprivation and Mortality in Bavaria. Development of a Community-Based Index of Multiple Deprivation]. *Gesundheitswesen* 2012; **74**: 416–425.

14 Kuznetsov L, Maier W, Hunger M, Meyer M, Mielck A. Associations between regional socioeconomic deprivation and cancer risk: Analysis of population-based Cancer Registry data from Bavaria, Germany. *Prev Med* 2011; **53**: 328–330.

15 Rathmann W, Haastert B, Icks A, Löwel H, Meisinger C, Holle R *et al.* High prevalence of undiagnosed diabetes mellitus in Southern Germany: target populations for efficient screening. The KORA survey 2000. *Diabetologia* 2003; **46**: 182–189.

16 Völzke H, Alte D, Schmidt CO, Radke D, Lorbeer R, Friedrich N *et al.* Cohort profile: the study of health in Pomerania. *Int J Epidemiol* 2011; **40**: 294–307.

17 Greiser KH, Kluttig A, Schumann B, Kors JA, Swenne CA, Kuss O *et al.* Cardiovascular disease, risk factors and heart rate variability in the elderly general population: design and objectives of the CARdiovascular disease, Living and Ageing in Halle (CARLA) Study. *BMC Cardiovasc Disord* 2005; **5**: 33.

18 Dragano N, Hoffmann B, Stang A, Moebus S, Verde PE, Weyers S *et al.* Subclinical coronary atherosclerosis and neighbourhood deprivation in an urban region. *Eur J Epidemiol* 2009; **24**: 25–35.

19 Vennemann MM, Hummel T, Berger K. The association between smoking and smell and taste impairment in the general population. *J Neurol* 2008; **255**: 1121–1126.

20 Schunk M, Reitmeir P, Schipf S, Völzke H, Meisinger C, Thorand B *et al.* Health-related quality of life in subjects with and without Type 2 diabetes: pooled analysis of five population-based surveys in Germany. *Diabet Med* 2012; **29**: 646–653.

21 Mielck A, Kiess R, von dem Knesebeck O, Stirbu I, Kunst AE. Association between forgone care and household income among the elderly in five Western European countries – analyses based on survey data from the SHARE-study. *BMC Health Serv Res* 2009; **9**: 52.

22 Mozaffarian D, Kamineni A, Carnethon M, Djousse L, Mukamal KJ, Siscovick D. Lifestyle risk factors and new-onset diabetes mellitus in older adults: the Cardiovascular Health Study. *Arch Intern Med* 2009; **169**: 798–807.

23 Merlo J, Chaix B, Ohlsson H, Beckman A, Johnell K, Hjerpe P *et al.* 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* 2006; **60**: 290–297.

24 Koppes LL, Dekker JM, Hendriks HF, Bouter LM, Heine RJ. Moderate alcohol consumption lowers the risk of type 2 diabetes: a meta-analysis of prospective observational studies. *Diabetes Care* 2005; **28**: 719–725.

25 Smith JP. The impact of socioeconomic status on health over the life course. *J Hum Resour* 2007; **XLII**: 739–764.

26 Ayyagari P, Grossman D, Sloan F. Education and health: evidence on adults with diabetes. *Int J Health Care Finance Econ* 2011; **11**: 35–54.

27 Schillinger D, Grumbach K, Piette J, Wang F, Osmond D, Daher C *et al.* Association of health literacy with diabetes outcomes. *J Am Med Assoc* 2002; **288**: 475–482.

28 Seligman HK, Laraia BA, Kushel MB. Food insecurity is associated with chronic disease among low-income NHANES participants. *J Nutr* 2010; **140**: 304–310.

29 Schulze MB, Schulz M, Heidemann C, Schienkiewitz A, Hoffmann K, Boeing H. Fiber and magnesium intake and incidence of type 2 diabetes: a prospective study and meta-analysis. *Arch Intern Med* 2007; **167**: 956–965.

30 Harding AH, Wareham NJ, Bingham SA, Khaw K, Luben R, Welch A *et al.* Plasma vitamin C level, fruit and vegetable consumption, and the risk of new-onset type 2 diabetes mellitus: the European prospective investigation of cancer—Norfolk prospective study. *Arch Intern Med* 2008; **168**: 1493–1499.

31 Darmon N, Drewnowski A. Does social class predict diet quality? *Am J Clin Nutr* 2008; **87**: 1107–1117.

32 Hu FB. Sedentary lifestyle and risk of obesity and type 2 diabetes. *Lipids* 2003; **38**: 103–108.

33 Steenhuis IH, Nooy SB, Moes MJ, Schuit AJ. Financial barriers and pricing strategies related to participation in sports activities: the perceptions of people of low income. *J Phys Act Health* 2009; **6**: 716–721.

34 Kruize H, Driessen PP, Glasbergen P, van Egmond KN. Environmental equity and the role of public policy: experiences in the Rijnmond region. *Environ Manage* 2007; **40**: 578–595.

35 Pearson JF, Bachireddy C, Shyamprasad S, Goldfine AB, Brownstein JS. Association between fine particulate matter and diabetes prevalence in the US. *Diabetes Care* 2010; **33**: 2196–2201.

36 Krämer U, Herder C, Sugiri D, Strassburger K, Schikowski T, Ranft U *et al.* Traffic-related air pollution and incident type 2 diabetes: results from the SALIA cohort study. *Environ Health Perspect* 2010; **118**: 1273–1279.

37 van Jaarsveld CH, Miles A, Wardle J. Pathways from deprivation to health differed between individual and neighborhood-based indices. *J Clin Epidemiol* 2007; **60**: 712–719.

38 Cox M, Boyle PJ, Davey PG, Feng Z, Morris AD. Locality deprivation and Type 2 diabetes incidence: a local test of relative inequalities. *Soc Sci Med* 2007; **65**: 1953–1964.

39 Braubach M, Fairburn J. Social inequities in environmental risks associated with housing and residential location—a review of evidence. *Eur J Public Health* 2010; **20**: 36–42.

40 Tamayo T, Christian H, Rathmann W. Impact of early psychosocial factors (childhood socioeconomic factors and adversities) on future risk of type 2 diabetes, metabolic disturbances and obesity: a systematic review. *BMC Public Health* 2010; **10**: 525.

41 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.

42 Espelt A, Goday A, Franch J, Borrell C. Validity of self-reported diabetes in health interview surveys for measuring social inequalities in the prevalence of diabetes. *J Epidemiol Community Health* 2012; **66**: e15.

43 Hoffmann W, Terschuren C, Holle R, Kamtsiuris P, Bergmann M, Kroke A *et al.* Zum Problem der Response in epidemiologischen Studien in Deutschland (Teil II) [The Problem of Response in Epidemiologic Studies in Germany (Part II)]. *Gesundheitswesen* 2004; **66**:482–491.

44 Chaix B, Billaudeau N, Thomas F, Havard S, Evans D, Kestens Y *et al.* Neighborhood effects on health: correcting bias from neighborhood effects on participation. *Epidemiology* 2011; **22**: 18–26.

45 Streiner DL, Norman GR. *Health Measurement Scales. A Practical Guide to their Development and Use*. 2nd edn. New York: Oxford University Press, 1995.

46 Ashfield-Watt PA, Welch AA, Godward S, Bingham SA. Effect of a pilot community intervention on fruit and vegetable intakes: use of FACET (Five-a-day Community Evaluation Tool). *Public Health Nutr* 2007; **10**: 671–680.