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Socioeconomic position and SARS-CoV-2 infections: seroepidemiological findings from a German nationwide dynamic cohort

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ABSTRACT

Background Evidence on the relationship between socioeconomic position (SEP) and infections with SARS-CoV-2 is still limited as most of the available studies are ecological in nature. This is the first German nationwide study to examine differences in the risk of SARS-CoV-2 infections according to SEP at the individual level.

Methods The 'CORONA-MONITORING bundesweit' (RKI-SOEP) study is a seroepidemiological survey among a dynamic cohort of the German adult population (n=15 122; October 2020–February 2021). Dried blood samples were tested for SARS-CoV-2 antibodies and oral-nasal swabs for viral RNA. SEP was measured by education and income. Robust logistic regression was used to examine adjusted associations of SARS-CoV-2 infections with SEP.

Results 288 participants were seropositive, PCR positive or self-reported a previous laboratory-confirmed SARS-CoV-2 infection. The adjusted odds of SARS-CoV-2 infection were 1.87-fold (95% CI 1.06 to 3.29) higher among low-educated than highly educated adults. Evidence was weaker for income differences in infections (OR=1.65; 95% CI 0.89 to 3.05). Highly educated adults had lower odds of undetected infection.

Conclusion The results indicate an increased risk of SARS-CoV-2 infection in low-educated groups. To promote health equity in the pandemic and beyond, social determinants should be addressed more in infection protection and pandemic planning.

INTRODUCTION

Initial research on the pandemic indicates that SARS-CoV-2 infections occur more frequently in socioeconomically deprived areas.¹ Infection risks may accordingly be higher for people in disadvantaged living and certain working conditions, especially during more advanced stages of the pandemic.^{2,3} For example, essential workers employed in the logistic, healthcare, retailing or public transport sector, who tend to have lower incomes than non-essential workers,⁴ often work in conditions involving closer physical proximity to others.⁵ The possibility to work remotely is, by contrast, more available to people with higher incomes and qualifications.⁶ Furthermore, crowded living conditions and limited access to effective personal protective equipment may increase the

risk of viral transmissions and thereby produce inequalities in infections.⁷

Research on socioeconomic differences in SARS-CoV-2 infections has been based mostly on ecological studies correlating area-level infection rates with area-level socioeconomic indicators.^{1,2,8,9} The advantage of ecological studies is that area-level data are available relatively quickly, for example, from existing surveillance systems. Ecological studies can thus be an expedient starting point for exploring the phenomenon. However, their findings are prone to ecological fallacy, areas can be very heterogeneous in terms of their residents' socioeconomic position (SEP) and inequalities are probably underestimated. Seroepidemiological individual-level studies are therefore needed to examine the relationship between SEP and SARS-CoV-2. In this study, we introduced serological and PCR testing along with a self-report questionnaire on previously conducted PCR tests into an existing German cohort and investigated whether SARS-CoV-2 infections were associated with SEP at the individual level.

METHODS

Study design

The 'CORONA-MONITORING bundesweit' study (RKI-SOEP study) is based on the nationwide population-based random samples administered by the German Socio-Economic Panel (SOEP), a dynamic cohort from Germany's resident population in private households.^{10,11} A gross sample of 31 675 adult cohort members was invited to participate, of which 15 122 individuals (response: 48%) participated in the study. The net sample comprised participants in 400 of the 401 German districts (Nomenclature of Territorial Units for Statistics [NUTS]-3 level), with an average of 38 participants per district.

Between October 2020 and February 2021, biospecimens and interview data were collected once from each participant. Participants provided a dried capillary blood sample obtained by finger prick to serologically detect antibodies from a previous SARS-CoV-2 infection by ELISA. To test for a current infection, participants provided an oral-nasal swab sample for PCR testing. Both specimens were collected by the participants themselves using CE-certified sample collection and submission



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kits sent by post along with written, pictorial and video instructions. A one-page paper questionnaire included questions on previous throat swab laboratory tests for SARS-CoV-2. Further details can be found in the study protocol.¹¹

Measures and definitions

We used three infection metrics based on combinations of the following: seropositivity for SARS-CoV-2 IgG antibodies from dried blood samples (Euroimmun SARS-CoV-2-S1 IgG-ELISA; cut-off adapted for dried blood spot testing; ratio ≥ 0.94),¹² a positive SARS-CoV-2-PCR test result in the study and any self-reported SARS-CoV-2-positive throat swab laboratory test conducted prior to study participation. Cases were defined as those meeting at least one of these criteria (ie, if participants had missing data or were not positive on one criterion but were positive on another, they were considered as cases). Undetected infection with SARS-CoV-2 was defined as having tested seropositive or PCR-positive during the study but self-reported never having had a SARS-CoV-2-positive swab test before.

SEP was measured using participants' self-reported prepan-demic (and hence exogenous) education and income from SOEP wave 2019 or the latest available from earlier waves. Using the CASMIN (Comparative Analysis of Social Mobility in Industrial Nations) educational classification,¹³ participants' highest school and vocational qualifications were classified into low (no, primary or low secondary education), middle (intermediate/high secondary education) and high (tertiary education). Equalised current disposable household income was calculated using the OECD (Organisation for Economic Co-operation and Development)-modified equivalence scale and categorised into low (<60% of median), middle (60%–<150% of median) and high ($\geq 150\%$ of median).¹⁴

Statistical analysis

The prevalence of SARS-CoV-2 infections was estimated using weighting factors to compensate for sampling design and non-random non-response. The weighting factors result from complex non-response modelling at the person and household level and calibration of the sample to match the official German population statistics by age, sex, federal state, municipality size, household size and owner-occupied housing. Standard error (SE) estimation was performed using Stata's survey data commands (V.17.0, StataCorp LLC, College Station, Texas, USA) accounting for weighting and household clustering. Logistic regression models with household-clustered SEs were used to estimate odds ratios (ORs) for SARS-CoV-2 infections by SEP, adjusted for a set of covariates: age, sex, household size, migrant background, urban–rural residence, region (east/west), date of participation and dummy variables for missing values.

RESULTS

Among the 15 122 participants aged 18–99 years, more than 80% participated in October and November 2020 (median participation date: 11 November 2020). Overall, 192 participants were seropositive, 51 were PCR positive and 146 self-reported having had a laboratory-confirmed SARS-CoV-2 infection before study participation (table 1). At least one of these criteria was met by 288 participants.

Table 2 shows the prevalence and adjusted ORs for SARS-CoV-2 infection by SEP. Seropositivity, seropositivity or PCR positivity and a self-reported positive swab test were each most prevalent in the lowest education and income groups. After adjusting for covariates, low education remained associated with

Table 1 Characteristics of the study population (n=15 122)

	n	%*
Sex		
Women	8099	50.9
Men	7023	49.1
Age group (years)		
18–34	2805	25.0
35–49	3553	22.7
50–64	4945	27.6
65–79	3126	18.4
80+	693	6.4
Education		
Low	3267	31.0
Middle	6326	41.9
High	4916	27.1
Missing	613	–
Income		
<60% of median	1524	15.2
60%–<150% of median	8406	57.6
$\geq 150\%$ of median	5065	27.2
Missing	127	–
Date of participation		
October 2020	5532	(36.6)
November 2020	6748	(44.6)
December 2020	2090	(13.8)
January 2021	595	(3.9)
February 2021	157	(1.0)
SARS-CoV-2 IgG antibodies		
Seropositive	192	1.3
Seronegative	14 589	98.7
Missing	341	–
SARS-CoV-2 RNA		
PCR positive	51	0.4
PCR negative	14 638	99.6
Missing	433	–
Previously tested positive for SARS-CoV-2†		
Yes	146	1.1
No	14 771	98.9
Missing	205	–

*Weighted percentage (unweighted percentage in brackets).

†Self-reported positive throat swab test before study participation.

seropositivity and the combined infection indicator of measured seropositivity or PCR positivity. A previously detected infection with SARS-CoV-2 as indicated by a self-reported positive swab test prior to the study showed no consistent association with either education or income. When all three infection parameters were combined (seropositive/PCR positive or previously tested positive), the OR for SARS-CoV-2 infection was 1.87-fold higher in the low than high education group. Evidence was weaker for income differences in infections. With regard to undetected infections, highly educated adults had lower odds of being seropositive or PCR positive without previously having received a positive swab test result compared with adults with low as well as those with medium education, net of all covariates. The adjusted OR comparing high versus low/middle education was 0.45 (95% CI 0.22 to 0.93, $p=0.031$).

Table 2 SARS-CoV-2 infection by socioeconomic position among adults in Germany, October 2020–February 2021

	% (95% CI)*	OR (95% CI)†	p value
Seropositive			
Education			
Low	1.80 (1.19 to 2.71)	2.32 (1.18 to 4.53)	0.014
Middle	0.98 (0.67 to 1.43)	1.20 (0.69 to 2.08)	0.527
High	1.01 (0.69 to 1.50)	Ref.	
Income			
<60% of median	2.04 (1.12 to 3.70)	1.56 (0.77 to 3.17)	0.220
60%–<150% of median	1.20 (0.87 to 1.66)	1.02 (0.58 to 1.79)	0.945
≥150% of median	1.02 (0.69 to 1.52)	Ref.	
Seropositive/PCR positive			
Education			
Low	2.05 (1.37 to 3.07)	2.03 (1.10 to 3.75)	0.024
Middle	1.46 (1.04 to 2.05)	1.45 (0.89 to 2.37)	0.140
High	1.21 (0.85 to 1.72)	Ref.	
Income			
<60% of median	2.69 (1.29 to 5.51)	1.58 (0.77 to 3.26)	0.213
60%–<150% of median	1.53 (1.15 to 2.04)	1.09 (0.65 to 1.82)	0.746
≥150% of median	1.18 (0.82 to 1.70)	Ref.	
Previously tested positive‡			
Education			
Low	1.39 (0.82 to 2.35)	1.68 (0.76 to 3.69)	0.197
Middle	0.84 (0.54 to 1.29)	0.87 (0.43 to 1.76)	0.694
High	1.17 (0.74 to 1.86)	Ref.	
Income			
<60% of median	1.99 (0.94 to 4.17)	1.42 (0.61 to 3.30)	0.418
60%–<150% of median	0.98 (0.68 to 1.42)	0.82 (0.40 to 1.69)	0.596
≥150% of median	1.06 (0.59 to 1.88)	Ref.	
Seropositive/PCR positive or previously tested positive			
Education			
Low	2.44 (1.71 to 3.48)	1.87 (1.06 to 3.29)	0.029
Middle	1.78 (1.31 to 2.42)	1.29 (0.78 to 2.14)	0.315
High	1.68 (1.18 to 2.39)	Ref.	
Income			
<60% of median	3.64 (2.10 to 6.24)	1.65 (0.89 to 3.05)	0.112
60%–<150% of median	1.81 (1.39 to 2.33)	0.95 (0.57 to 1.56)	0.827
≥150% of median	1.63 (1.09 to 2.43)	Ref.	
Undetected infection			
Education			
Low	1.00 (0.60 to 1.66)	2.17 (0.90 to 5.25)	0.085
Middle	0.91 (0.58 to 1.43)	2.27 (1.03 to 5.00)	0.042
High	0.51 (0.29 to 0.89)	Ref.	
Income			
<60% of median	1.56 (0.75 to 3.24)	1.77 (0.81 to 3.83)	0.150
60%–<150% of median	0.77 (0.52 to 1.13)	1.03 (0.54 to 1.96)	0.855
≥150% of median	0.64 (0.41 to 1.00)	Ref.	

*Prevalence (weighted).

†Adjusted for age, sex, household size, migrant background, urban–rural residence, region (east/west), date of participation and dummies for missing values (separate models for education and income).

‡Self-reported positive throat swab test before study participation.

Ref, reference group.

DISCUSSION

This is the first German nationwide study of SEP differences in SARS-CoV-2 infections based on individual-level data from the pandemic. The results indicate an increased risk of infection among low-qualified adults and that undetected infections were least common among the highly educated.

The seroepidemiological design enabled the detection of known infections and infections that had previously gone undetected, for example, in asymptomatic cases. Moreover, adding PCR to serological testing was especially relevant because the specimens were collected during the ongoing second wave of SARS-CoV-2 infections in Germany, in which seroconversion from infections in this wave was still in progress. Completely non-random non-response could be counteracted by complex weighting, which enabled extrapolation to Germany's adult population in private households. As both SEP and infection variables were measured at the individual level, this study can contribute to overcoming the limitations of previous ecological studies, such as the possibility of ecological fallacy.

An important limitation is that the sample was restricted to residents in private households. Institutionalised people, such as nursing home residents or people living in shared accommodations for homeless people, migrant workers or asylum seekers, are not represented. Assuming increased infection risks in these groups, this study may have underestimated socioeconomic differences in infections. Selection bias may have occurred if individuals with SARS-CoV-2 infection were more or less willing to participate in the study and if this varied by SEP. Depending on the direction of this potential effect, it may have led to overestimation or underestimation of SEP differences in infections. Conditions that may alter immune response, for example, immunosuppressive therapy or obesity, could not be controlled for in the serological testing, which may have been another source of bias.

Our findings support evidence from earlier pandemics of viral respiratory pathogens, such as influenza, suggesting higher levels of viral exposure in low-SEP settings.⁷ Consistent with our findings, higher levels of SARS-CoV-2 infections in low-educated individuals have been found in the UK Biobank and a seroprevalence survey in five German regions.^{15 16} However, individual-level nationwide findings on SEP differences in SARS-CoV-2 infections during the pandemic are still scarce and sometimes contrary.^{17 18} Important mediators in the relationship between education

What is already known on this subject

- ▶ Initial research on the pandemic indicates that SARS-CoV-2 infections are more common in socioeconomically deprived areas.
- ▶ Individual-level studies on socioeconomic differences in SARS-CoV-2 infections during the pandemic are still scarce, and their findings are sometimes inconsistent or contradictory.

What this study adds

- ▶ This is the first German nationwide study of socioeconomic differences in SARS-CoV-2 infections based on individual-level data from the pandemic. We found a higher risk of infection among adults with low education. Infections were least likely to go undetected among the highly educated. Our analysis identified low-educated adults as an important target group for infection protection, testing and control strategies during pandemics involving novel viral respiratory pathogens.

and infections may be occupational working conditions.¹⁹ People in medium-skilled to low-skilled occupations such as nursing, retailing, production or logistics, had few opportunities to reduce occupational contact and mobility by working remotely during the pandemic and are associated with more contact and proximity with others. Moreover, campaigns to educate people about infection protection may have been less effective in reaching low-literate groups, and highly educated people may have had better opportunities in their everyday circumstances to implement infection control measures, such as physical distancing or regular testing.

Our findings indicate an increased risk of SARS-CoV-2 infection in educationally disadvantaged groups and suggest a higher detection of infections among highly educated adults. Infection control strategies should provide universal access to testing that is independent of socioeconomic background from early on. To promote health equity in the pandemic and beyond, social determinants should be given more recognition in infection protection and pandemic planning.

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Contributors All authors of this work meet the ICMJE Authorship Criteria. MMG, SZ, SL and JH made substantial contributions to the design of the study. JH conducted the statistical analysis and drafted the manuscript with substantial contributions from SZ, MMG, BW, CS, SH and HN. All authors substantially contributed to the interpretation of data, edited the manuscript and revised it critically for important intellectual content. All authors approved the final manuscript.

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Patient consent for publication Not applicable.

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