Neighbourhood socio-economic vulnerability and access to COVID-19 healthcare during the first two waves of the pandemic in Geneva, Switzerland: A gender perspective

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Summary

Background Neighbourhood socio-economic inequities have been shown to affect COVID-19 incidence and mortality, as well as access to tests. This article aimed to study how associations of inequities and COVID-19 outcomes varied between the first two pandemic waves from a gender perspective.

Methods We performed an ecological study based on the COVID-19 database of Geneva between Feb 26, 2020, and June 1, 2021. Outcomes were the number of tests per person, the incidence of COVID-19 cases, the incidence of COVID-19 deaths, the positivity rate, and the delay between symptoms and test. Outcomes were described by neighbourhood socio-economic levels and stratified by gender and epidemic waves (first wave, second wave), adjusting for the proportion of inhabitants older than 65 years.

Findings Low neighbourhood socio-economic levels were associated with a lower number of tests per person (incidence rate ratio [IRR] of 0.88, 0.85 and 0.83 for low, moderate, and highly vulnerable neighbourhood respectively), a higher incidence of COVID-19 cases and of COVID-19 deaths (IRR 2.3 for slightly vulnerable, 1.9 for highly vulnerable). The association between socio-economic inequities and incidence of COVID-19 deaths was mainly present during the first wave of the pandemic, and was stronger amongst women. The increase in COVID-19 cases amongst vulnerable populations appeared mainly during the second wave, and originated from a lower access to tests for men, and a higher number of COVID-19 cases for women.

Interpretation The COVID-19 pandemic affected people differently depending on their socio-economic level. Because of their employment and higher prevalence of COVID-19 risk factors, people living in neighbourhoods of lower socio-economic levels, especially women, were more exposed to COVID-19 consequences.

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Introduction

Almost 2 years after its emergence, the COVID-19 pandemic has taken the lives of more than 5.9 million people worldwide[1] and is still, as of February 2022, an active threat. The COVID-19 illness can affect anyone

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Research in context

Evidence before this study

We searched for cohort and ecological studies published up to June 1, 2021 within the global literature on COVID-19 collected by WHO (search.bvsalud.org/global-literature-on-novel-coronavirus-2019-ncov) with the terms socio* AND (disp* OR ineq* OR vuln*). We also searched for references cited in relevant publications. Existing studies report lower testing, higher case incidence, higher positivity, higher incidence of hospitalization, and higher death incidence from COVID-19 amongst populations with low incomes and from areas with high inequities. No study specifically studied the variation of these associations with gender.

Added value of this study

Using a database gathering all SARS-CoV-2 tests of a population of half a million people in Geneva, Switzerland, we showed that poor neighbourhood socio-economic conditions are associated with a lower rate of testing, and a higher incidence, positivity, and death incidence from COVID-19. This association varied greatly between the first and the second wave of the pandemic. The association between neighbourhood socio-economic conditions and COVID-19 death incidence was stronger for women, whereas the association with testing capacities was lower.

Implications of all the available evidence

The association between neighbourhood socio-economic conditions and COVID-19 mortality and access to healthcare stems in part from the occupational settings and the economic and health policies of the population. This highlights the importance of equity in access to health services and suggests targets for public health measures.

but risk factors associated with severe symptoms are now better known. Being a man,[2,3] having chronic conditions,[2] frailty,[4] socio-economic conditions,[2,5] housing and living conditions,[6] occupations,[7] the ability to work at home and the use of public transportations,[8] ethnicity and migrant status[9] and access to the healthcare system affect the probability of being infected by the SARS-CoV-2 virus, of being hospitalised and of dying from the COVID-19 illness.[10] The COVID-19 pandemic did not spread uniformly across communities,[11] leading to growing inequalities in infection and mortality.[5] Though equitable care and access to care is always important, in the case of infectious diseases, it is also crucial to prevent new waves of infections.[12] Socio-economically disadvantaged communities are rendered vulnerable through an accumulation of social conditions that may increase the impact of the pandemic on these communities. Indeed, the COVID-19 incidence has been shown to be higher in neighbourhoods with disadvantaged socio-economic conditions in multiple countries, such as in Switzerland,[5] in the USA,[13,14] in Spain (Barcelona),[15] in Peru (Lima),[16] Italy,[17] France[18] and India.[19] Spatial socio-economic inequities have been shown to affect COVID-19 incidence, related deaths, but also access to tests and positivity in three large US cities,[20] in France[18] and in Switzerland.[5] Furthermore, due to the learning and adaptation capacity of health systems and public health authorities between the first and subsequent waves, the impact of the COVID-19 pandemic varies over time, and this was observed in a study in the USA where the association between income and COVID-19 outcome appears to change over time.[22]

Furthermore, although gender differences in risk of SARS-CoV-2 infection have been documented,[2,21,22] the potential role that they might play at the intersection with socio-economic conditions at the community level remains to be explored. In this paper, we define gender as an institutionalised system of social practices for constituting people as two significantly different categories, men and women.[23] Because of their social roles and distribution within the workforce, women represent a majority of healthcare workers and tend to have more family caring responsibilities, all factors which could increase their exposure to SARS-CoV-2.[24] Characterising the role of neighbourhood-level social inequities, their change over time and interplay with gender during the COVID-19 pandemic is a key point for effective and appropriate public health interventions to prevent adverse outcomes and redress health inequities.[25] Using the state register ARGOS,[26] we performed an ecological study examining the association between COVID-19 related outcomes, COVID-19 testing capacities and neighbourhood-level socio-economic inequities in a region of half a million people. We focus on how these associations vary over time and across gender.

Methods

Design

The design of this study is a population-based ecological study. It uses the ARGOS database,[26] which is an ongoing prospective cohort created by the Geneva health state agency (Geneva Directorate of Health) and consists of an operational database compiling all SARS-CoV-2 test results conducted in the state of Geneva. The register contains baseline, follow-up, and contact information of all COVID-19 positive tested persons (57 438 positive cases between the first case on Feb 26, 2020, and June 1, 2021, 242 821 negative cases) residing in the State of Geneva, Switzerland. Geneva is a state of around 507 600 inhabitants (in January 2021), mainly urban, with a high population density, which doubles its population on working days (excluding pandemic restrictions) as a result of national and international commuter traffic (mainly from neighbouring France). We used the ARGOS database to assess the number of tests, confirmed cases, deaths, and delay between test and symptoms by gender, epidemic wave, and neighbourhood in the State of Geneva. Gender was self-reported: participants could choose between the categories 'man', 'woman' and 'other'. The gender category 'other' was not included in our analysis, due to the very low number of cases in the time range studied (33 cases). People tested in Geneva but not living in Geneva were not included in the present analysis. We define two main time periods according to the evolution of the pandemic in Geneva: the first wave, corresponding to the surge of COVID-19 between Feb 26 and July 1, 2020, and the second wave, spanning from July 2, 2020 to June 1, 2021.

The statistical office of Geneva divides the territory in 476 areas at the neighbourhood level (hereafter neighbourhood), with a median [IQR] population of 1060 persons [436, 1919] and a median [IQR] surface of 0.43 [0.14, 0.55] km² (see Table 1). The present ecological study is performed at this neighbourhood level: the outcomes are calculated for each neighbourhood, the covariates are provided for each neighbourhood, and thus the dataset used for the analysis contained one row per neighbourhood.

To do so, each entry (person) of the ARGOS database was localised with its address and assigned to one neighbourhood, using the official list of 53 226 official addresses of the state of Geneva.[27] 5.3% of the addresses of the patients tested positive for SARS-CoV-2 could not be recovered, as well as 12.0% of those negative, but their postal code was available. There are 61 different postal codes in Geneva, corresponding to geographic zones containing a median number [IQR] of 5 [4,11] neighbourhood and 738 [352, 1313] addresses. We used multiple imputation[28] to handle missing data. We generated 50 imputed datasets at the neighbourhood level, where patients with missing or wrong addresses were randomly attributed to a neighbourhood corresponding to their postal code. This sampling process was weighted with a probability given by the population of the neighbourhood. The statistical analyses were performed on each imputed dataset and the results were then pooled according to Rubin's law.[29]

Neighbourhood and population	
Number of neighbourhoods	368
Surface of the neighbourhood (km^2)	0.43 [0.14, 0.55]
Percentage of the population above 65 years	16.90 [13.4, 20.8]
Population of the neighbourhood	1060 [436, 1919]
Population of men in the neighbourhood	513 [211, 923]
Population of women in the neighbourhood	543 [219, 994]
COVID-19	
Incidence of COVID-19 cases (per hundred inhabitant)	9.20 [8.10, 10.50]
Test incidence (per inhabitant)	0.77 [0.70, 0.90]
Positivity rate	12.0 [10.1, 14.0]
Death Incidence (per 10,000 inhabitants)	5.65 [0.00, 14.22]
Mean delay between symptoms and test (days)	3.14 [2.85, 3.40]
Vulnerability	
percentage of beneficiaries of housing allowance	1.10 [0.00, 3.26]
median income (CHF)	147,000 [111,747, 185,729]
percentage of low income	21.25 [15.30, 27.20]
percentage of student coming from a modest family	26.56 [13.88, 39.58]
Percentage of unemployment	3.31 [2.30, 4.20]
Percentage of persons perceiving social subsidies	7.45 [3.70, 11.83]
Vulnerability score (%)	
Reference (score 0)	176 (47.8)
slightly vulnerable (score 1)	62 (16.8)
vulnerable (score 2 or 3)	61 (16.6)
highly vulnerable (score 4, 5 or 6)	69 (18.8)

***Table 1*: Statistics (median [inter-quartile range] or Number (percentage)) at the neighbourhood level in the state of Geneva, concerning population of the neighbourhoods, COVID-19 related outcomes and vulnerability.**

Ethics approval and consent to participate

Research received the agreement of the Cantonal Ethic Committee of Geneva (CCER protocol 2020–01,273). Individuals who refused to share their data were removed from the analysis.

Outcomes

For each neighbourhood, gender and time period, incidence of COVID-19 cases was assessed by the number of cases divided by the population of men or women in this area. Persons were only counted once, irrespective of the number of positive tests. Thus, reinfections were not included as additional cases.

Incidence of tests was calculated as the total number of tests (positive or negative, PCR or antigenic) performed by the persons living in the neighbourhood divided by the population of interest (men, women, or all) of this area.

The incidence of COVID-19 deaths was calculated as the number of death associated with COVID-19 by the official Swiss authorities in the neighbourhood divided by the population of interest.

Positivity ratio of Sars-Cov-2 was defined as the ratio between the number of positive cases and the total number of tests performed within the population in the neighbourhood.

In the ARGOS database, 85% of the positive patients had at least one follow-up call, during which they were asked if they had symptoms, and if yes at which date. The mean delay between date of test result and date of the first symptoms were then calculated within each neighbourhood.

Spatial distribution of the outcomes can be found in Figure 1.

Exposures

Socio-economic vulnerability was assessed using a neighbourhood socio-economic vulnerability index (NSVI) defined by the centre for Territorial Analysis of Inequalities (CATI-GE).[30] The state of Geneva provided for each neighbourhood 6 variables corresponding to different aspects of vulnerability: the proportion of household perceiving a housing allowance, the median income of households, the share of low income, the share of students coming from a modest family, the share of active persons registered to the unemployment office, and the share of persons perceiving social subsidies (e.g., disability subsidies, health insurance subsidies, or supplementary pension benefits). These variables are summarized in the supplementary Table S1, which provides the threshold used to determine if the variable contribute the socio-economic vulnerability.

The NSVI for each neighbourhood was operationalised as the sum of the six dichotomised variables (1 low socio-economic level, 0 non-low socio-economic level), resulting in a score ranging from 0 to 6. In order to have similar sizes of group, we defined four vulnerability groups: the reference group of neighbourhood with an NSVI equal to 0, slightly vulnerable neighbourhood with an NSVI of 1, moderately vulnerable neighbourhoods with an NSVI between 2 and 3, and highly vulnerable neighbourhood with a NSVI higher than 3. Spatial distribution of this score can be found in Figure 1.

Confounders

Given that age above 65 years is one of the major risk factor for COVID-19[21] and that a larger proportion of retired persons may have socio-economic difficulties, we used the proportion of person above 65 years as a confounder.

Statistical analysis

All the statistical spatial analyses were performed using R,[31] *data.table* for data management, the package *spatialreg*[32] for the spatial regression models, *sp* and *sf*[33] to handle spatial data. Spatial autocorrelation of the outcomes was assessed using Moran's Index.

When the outcome was the number of tests, the number of COVID-19 cases or of COVID-19 related deaths, the associations between the outcome and the covariates were assessed using a generalised negative binomial regression model to account for over dispersion. The incidence for these three outcomes was obtained by offsetting the regression with the neighbourhood population of interest.

When the outcome was the positivity rate or the delay between symptoms and test, the associations between the outcome and the covariates were assessed using standard linear model. When the outcome was the mean delay between symptoms and test, the regression was weighted by the number of available measures of delay in each neighbourhood.

For all regression, Moran's index of the residuals was computed to ensure that there was no residual spatial correlation left.

Policies may affect men and women differently, and disease incidence may vary by gender[34] therefore all associations between socio-economic vulnerability and COVID-19 related outcomes were examined separately for each wave and gender.

Role of the funding source

The funder had no role in study design; in the collection, analysis, and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication. DM, SR and DSC had full access to dataset. All authors were responsible for the decision to submit for publication.

Results

There were 57 438 positive cases (excluding repeated infections) of COVID-19 in people living in Geneva during the period studied (11.3% of the population). 769 of these individuals died of COVID-19 since the beginning of the pandemic (0.14% of the population).

In Geneva state, 242 821 residents tested negative (47.8% of the population), and 565 488 tests were performed. Table 2 details these numbers per epidemic wave for men and women. Amongst the 368 neighbourhoods of more than 90 people, 47.8% had a vulnerability score of 0 (Table 1). Figure 1 panel **a** presents the vulnerability score for the considered neighbourhoods. Neighbourhoods in Geneva had a median incidence of 9.2 cases per hundred inhabitants since the beginning of the pandemic, a median incidence of 0.77 test per inhabitant, a median positivity rate of 12%, and a median incidence of COVID-19 deaths of 0.056 per hundred inhabitants. The median mean delay between symptoms and tests was of 3.1 days.

The percentage of COVID-19 associated risk factors reported by positive COVID-19 cases increases with the NSVI (see Figure 2 panel **a**). Regarding occupations in Geneva, jobs including contact with the public such as receptionists, nursing, health care aids, cashiers, housekeepers, and service staff are mainly occupied by women (see Figure 2 panel **b**).

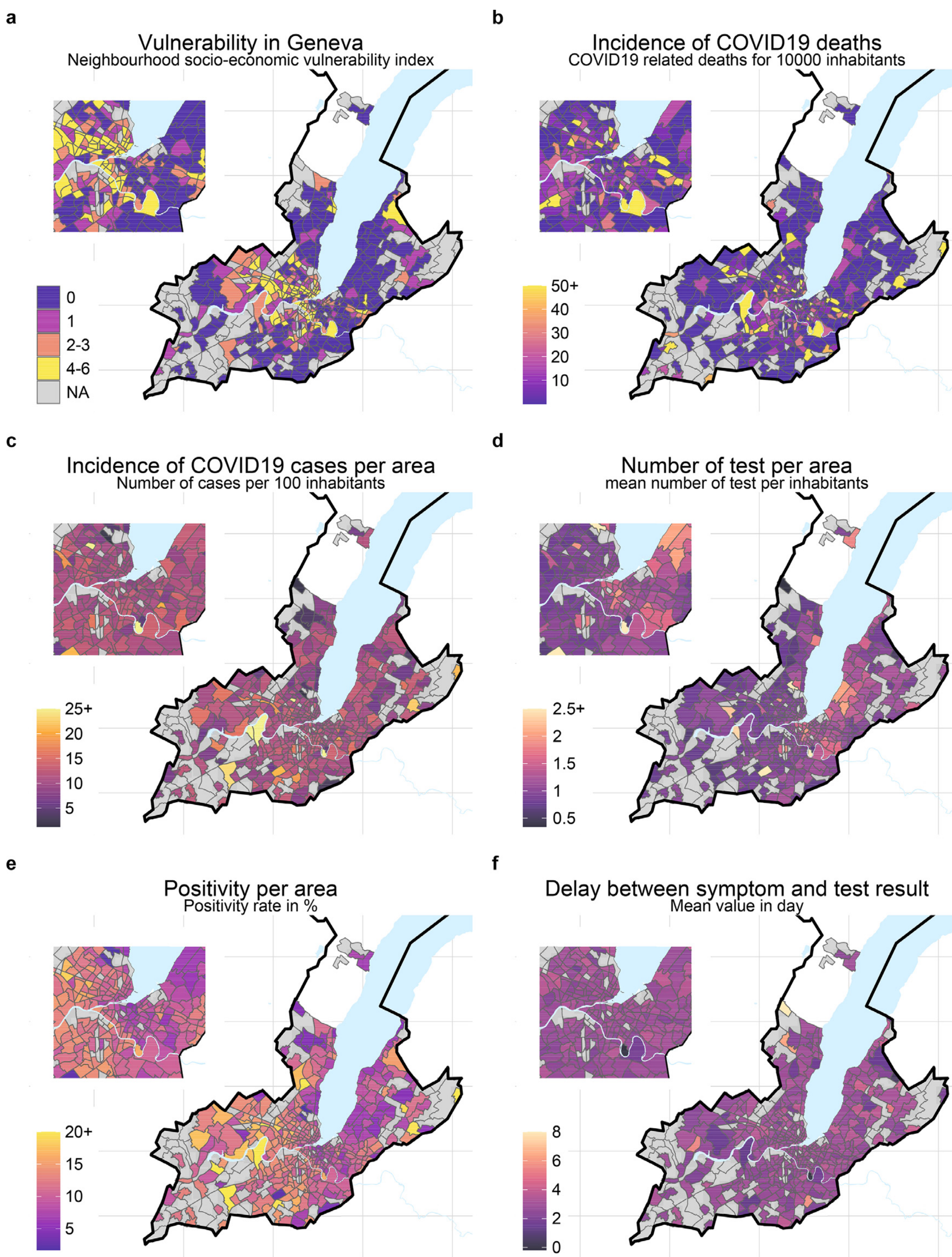

Figure 1. Geographical distribution over the 368 neighbourhoods of the canton of Geneva considered for the neighbourhood vulnerability index (panel **a**), the incidence of COVID-19 deaths (number of deaths per 10,000 inhabitants, panel **b**), the incidence of COVID-19 cases (number of cases per 100 inhabitants, panel **c**), the mean number of tests per person (panel **d**), the positivity rate (in percent, panel **e**) and the mean delay between symptom date and testing date (in days, panel **f**) since the first positive test recorded (Feb 26, 2020) until June 1, 2021.

variable	First wave		Second wave		All
	Men	Women	Men	Women	
	246,173	261,483	246,173	261,483	507,656
Number of tests	12,373	15,265	250,820	287,030	565,488
Number of deaths	148 (0.06%)	131 (0.05%)	240 (0.1%)	213 (0.08%)	732 (0.14%)
COVID-19 cases	2327 (0.9%)	2846 (1%)	24,456 (9.9%)	27,809 (10.6%)	57,438 (11.3%)

***Table 2*: Number of tests and number of identified COVID-19 cases in Geneva with an identified location, per wave for men and women.**

Overall results

The vulnerable neighbourhoods of Geneva had a higher incidence of COVID-19 deaths (see Table 3) when compared to reference neighbourhoods (which had a mean of 390 deaths per million inhabitants): moderately vulnerable neighbourhoods had an incidence of COVID-19 death multiplied by 2.3 [95% CI 1.6, 3.2], and highly vulnerable neighbourhoods by 1.9 [95% CI 1.4, 2.7]. The proportion of inhabitants older than 65 years significantly contributed to the incidence of COVID-19 deaths: an increase of 10% of the population older than 65 years in a neighbourhood increased the COVID-19 death incidence by a factor 2.1.

Vulnerable neighbourhoods had a lower incidence of testing, with a clear dose-response effect: when compared to the reference neighbourhoods (which had 0.6 tests per person on average), slightly vulnerable neighbourhoods had their number of tests per person multiplied by 0.88 [0.82, 0.96] when compared with reference neighbourhoods, moderately vulnerable neighbourhoods by 0.85 [95% CI 0.80, 0.92] and highly vulnerable neighbourhoods by 0.82 [95% CI 0.77, 0.90]. The proportion of people over 65 years increased slightly the testing incidence, with a multiplication of 1.07 every increase of 10% of the proportion of people older than 65 years.

Incidence of COVID-19 cases increased for moderately vulnerable and highly vulnerable neighbourhoods, with a multiplication of 1.1 of the COVID-19 cases incidence when compared to reference neighbourhoods (53 cases per 100 inhabitants). As a consequence of this incidence increase and of the decrease of testing, the positivity rate significantly increased with vulnerability (see Table 4), with a clear dose-response effect: when compared to reference neighbourhoods (with a mean positivity of 13.5%), the positivity rate increased by 1.6% [95% CI 0.6, 2.6] for slightly vulnerable neighbourhood, and up to 2.8% [95% CI 1.9,3.8] for highly vulnerable neighbourhoods.

The mean delay between tests and symptoms did not vary with vulnerability. Though this delay significantly decreased with the proportion of older residents, the

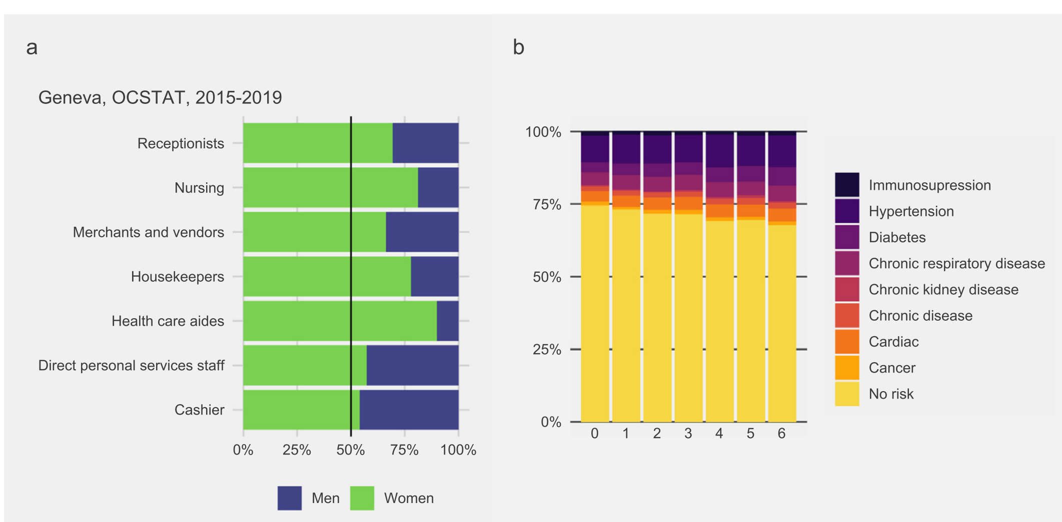

Figure 2. Panel **a**: Percentage of known COVID19 risk factors expressed by the positive COVID-19 cases as a function of the vulnerability score of their living neighbourhood. Panel **b**: Share of men (blue) and women (green) for job types in contact with public in Geneva. Percentage is rectified for the difference of working population amongst men and women.

Time period	Characteristics of neighbourhoods	Death incidence	Test incidence	Cases incidence
		Men and women		
Overall	Slightly vulnerable	1.45 [0.98,2.14]	0.88** [0.82,0.96]	1.07* [1.0004,1.14]
	moderately vulnerable	2.26*** [1.58,3.22]	0.85** [0.80,0.92]	1.13*** [1.06,1.21]
	Highly vulnerable	1.92*** [1.37,2.68]	0.83*** [0.77,0.90]	1.12*** [1.06,1.19]
	Proportion> 65 years	1.08*** [1.06,1.09]	1.007*** [1.003,1.01]	1.01*** [1.008,1.01]
		Women		
First wave	Slightly vulnerable	2.04 [0.87,4.74]	0.99 [0.89,1.09]	0.95 [0.81,1.12]
	moderately vulnerable	4.52*** [2.18,9.36]	1.24*** [1.12,1.37]	1.45*** [1.26,1.68]
	Highly vulnerable	2.97** [1.47,6.03]	1.18*** [1.08,1.30]	1.38*** [1.21,1.57]
	Proportion > 65 years	1.06*** [1.04,1.09]	1.02*** [1.02,1.03]	1.03*** [1.03,1.04]
		Men		
	Slightly vulnerable	1.47 [0.77,2.82]	0.98 [0.87,1.11]	1.01 [0.86,1.19]
	moderately vulnerable	2.61*** [1.52,4.49]	1.05 [0.93,1.18]	1.23** [1.06,1.42]
	Highly vulnerable	1.80* [1.06,3.04]	1.01 [0.90,1.13]	1.18* [1.03,1.34]
	Proportion > 65 years	1.07*** [1.06,1.09]	1.02*** [1.02,1.03]	1.04*** [1.03,1.04]
		Women		
Second wave	Slightly vulnerable	0.99 [0.52,1.88]	0.90*** [0.84,0.96]	1.09** [1.02,1.17]
	moderately vulnerable	1.52 [0.87,2.67]	0.94 [0.88,1.0006]	1.11** [1.04,1.19]
	Highly vulnerable	1.35 [0.80,2.27]	0.89*** [0.84,0.95]	1.15*** [1.08,1.22]
	Proportion > 65 years	1.08*** [1.06,1.10]	1.006*** [1.003,1.009]	1.005** [1.002,1.008]
		Men		
	Slightly vulnerable	1.25 [0.75,2.10]	0.87** [0.79,0.96]	1.05 [0.99,1.12]
	moderately vulnerable	1.45 [0.90,2.32]	0.82*** [0.74,0.90]	1.04 [0.98,1.11]
	Highly vulnerable	1.64* [1.08,2.50]	0.76*** [0.69,0.83]	1.03 [0.98,1.089]
	Proportion > 65 years	1.07*** [1.05,1.08]	1.004* [1.00008,1.008]	1.006*** [1.003,1.009]

Table 3*: Incidence rate ratio [Confidence Interval] for the vulnerability categories compared to the reference category and for an increase of 1% of the proportion of population over 65 years when predicting the COVID-19 related death incidence, test incidence and cases incidence, during the whole period of interest (Overall, February 26, 2020 until June 1, 2021) for both men and women, and stratified by epidemic wave (First wave: Feb 26, 2020 to July 1, 2020, Second wave: July 2, 2020 to June 1, 2021) and gender. Incidence is calculated as the number of deaths, tests or cases divided by the population of interest (men and women, men, or women) of each neighbourhood. "*" indicates a p value 0.05>p > 0.01, "**" 0.01>p > 0.001, and "" p < 0.001.**

effect size was very small, with a coefficient representing a decrease of less than 2 h of the delay for an increase of 10% of this at risk population.

Stratification by wave and gender

The stratification by wave and gender reveals clear differences between men and women and between the two epidemic waves.

First wave

During the first wave, the incidence of deaths was higher in vulnerable neighbourhoods for men and women (see Table 3). Furthermore, the difference between vulnerable neighbourhoods and reference neighbourhoods was larger for women than for men ($p < 0.001$): for moderately vulnerable neighbourhoods, the COVID-19 deaths incidence was multiplied by 4.5 [95% CI 2.2, 9.3] for women (compared with reference neighbourhoods having a mean COVID-19 death incidence of 1.8), whereas it was multiplied by 2.6 for men (when compared to the reference neighbourhoods with a mean of 2.7).

For access to tests, the number of tests per person was significantly associated with vulnerability amongst women: women in vulnerable neighbourhoods were more likely to be tested than those in reference neighbourhoods (see Figure 3 panel **a**). This was not the case for men. The incidence of COVID-19 positive cases was higher for men and women in vulnerable neighbourhoods, with a stronger association amongst women ($p < 0.001$).

The positivity rate did not show any clear association with vulnerability indices (see Table 4). Amongst men, the mean time between symptoms and test was shorter for more vulnerable neighbourhoods, with a dose-response effect: moderately vulnerable neighbourhoods had 1.0 days [95% CI 0.2, 1.8] less delay between symptoms and tests than the reference neighbourhoods, when the difference was of 1.4 days [95% CI 0.7, 2.0] for highly vulnerable neighbourhoods (Table 4). In contrast, the mean delay for women remained similar for all vulnerability neighbourhood.

Time period	Characteristics of neighbourhoods	Positivity	Mean test-symptom delay
		Men and women	
Overall	Slightly vulnerable	1.60** [0.65,2.60]	−0.07 [−0.17,0.02]
	moderately vulnerable	2.50*** [1.50,3.40]	−0.06 [−0.15,0.03]
	Highly vulnerable	2.80*** [1.90,3.80]	−0.05 [−0.12,0.03]
	Proportion> 65 years	0.03 [−0.01,0.07]	−0.007* [−0.01,−0.001]
		Women	
First wave	Slightly vulnerable	−1.05 [−4.53,2.44]	−0.18 [−1.06,0.70]
	moderately vulnerable	0.82 [−2.66,4.31]	−0.22 [−1.01,0.56]
	Highly vulnerable	2.48 [−0.87,5.82]	−0.65 [−1.31,0.02]
	Proportion > 65 years	0.08 [−0.07,0.23]	−0.03 [−0.08,0.02]
		Men	
	Slightly vulnerable	−1.14 [−4.30, 2.01]	−0.57 [−1.44,0.30]
	moderately vulnerable	3.79* [0.66,6.92]	−0.99* [−1.77,−0.20]
	Highly vulnerable	0.86 [−2.12,3.84]	−1.36*** [−2.04,−0.68]
	Proportion > 65 years	0.13 [0.0004,0.27]	0.02 [−0.03,0.06]
		Women	
Second wave	Slightly vulnerable	1.65** [0.55,2.75]	−0.04 [−0.16,0.08]
	moderately vulnerable	2.36*** [1.26,3.46]	−0.05 [−0.17,0.06]
	Highly vulnerable	2.80*** [1.72,3.87]	−0.02 [−0.12,0.08]
	Proportion > 65 years	−0.02 [−0.06,0.03]	−0.01*** [−0.02,−0.005]
		Men	
	Slightly vulnerable	1.88** [0.70,3.06]	−0.08 [−0.20,0.04]
	moderately vulnerable	2.01*** [0.83,3.19]	−0.05 [−0.16,0.06]
	Highly vulnerable	2.57*** [1.42,3.72]	−0.009 [−0.10,0.09]
	Proportion > 65 years	0.02 [−0.03,0.07]	−0.004 [−0.01,0.004]

Table 4*: Relative contribution [Confidence Interval] of the vulnerability categories when compared to the reference category and of an increase of 1% of the proportion of the population over 65 years when predicting the positivity and the mean delay between symptoms and test (in days) during the whole period of interest (Overall, February 26, 2020 until June 1, 2021) for both men and women, and stratified by epidemic wave (First wave: Feb 26, 2020 to July 1, 2020, Second wave: July 2, 2020 to June 1, 2021) and gender. "*" indicates a p value 0.05>p > 0.01, "**" 0.01 >p> 0.001, and "" p < 0.001.**

Second wave

During the second wave, the association between vulnerability and death incidence was reduced for both men and women. The effect was no longer significant for women, and remained, although weaker, for men (death incidence multiplied by 1.6 [95% CI 1.1, 2.5] for highly vulnerable neighbourhoods, see Table 3). It should be noted that the reference neighbourhoods had a higher death incidence during the second wave (mean death incidence of 509 per million inhabitants for women, 599 per million inhabitants for men, see Fig. 3 panel **d**).

A strong association was apparent between the proportion of population above 65 years and COVID-19 related deaths in men and women, although women's association increased compared to wave 1 ($p < 0.001$).

Positivity rate increased in similar proportion with vulnerability for men and women (dose response effect ranging from 1.6 to 2.5 percent increase when compared to reference neighbourhoods, see Table 4), but for different reasons. For women, the association between positivity and vulnerability is mainly due to a graded relationship between vulnerability and case-incidence (incidence of COVID-19 cases are multiplied by 1.09, 1.11 and 1.15 for slightly vulnerable, moderately vulnerable and highly vulnerable neighbourhoods), combined with a slight decrease of the testing. For males, the COVID-19 case incidence did not yield any association with vulnerability, but a clear decrease of the test incidence was observed for vulnerable neighbourhoods, reaching a division per 1.3 of the number of tests per person in the most vulnerable neighbourhoods.

During the second wave, the mean delay between symptoms and tests decreased overall by a factor of 1.8 when compared with the first wave, and had a much lower dispersion between neighbourhoods (see Fig. 3, panel **e**). It did not present any association with vulnerability anymore.

Discussion

In this register of all declared tests in an neighbourhood of half a million inhabitants, neighbourhood socio-economic vulnerability was associated with an increased incidence of death, a lower incidence of testing, a higher incidence of COVID-19 cases, and a higher positivity

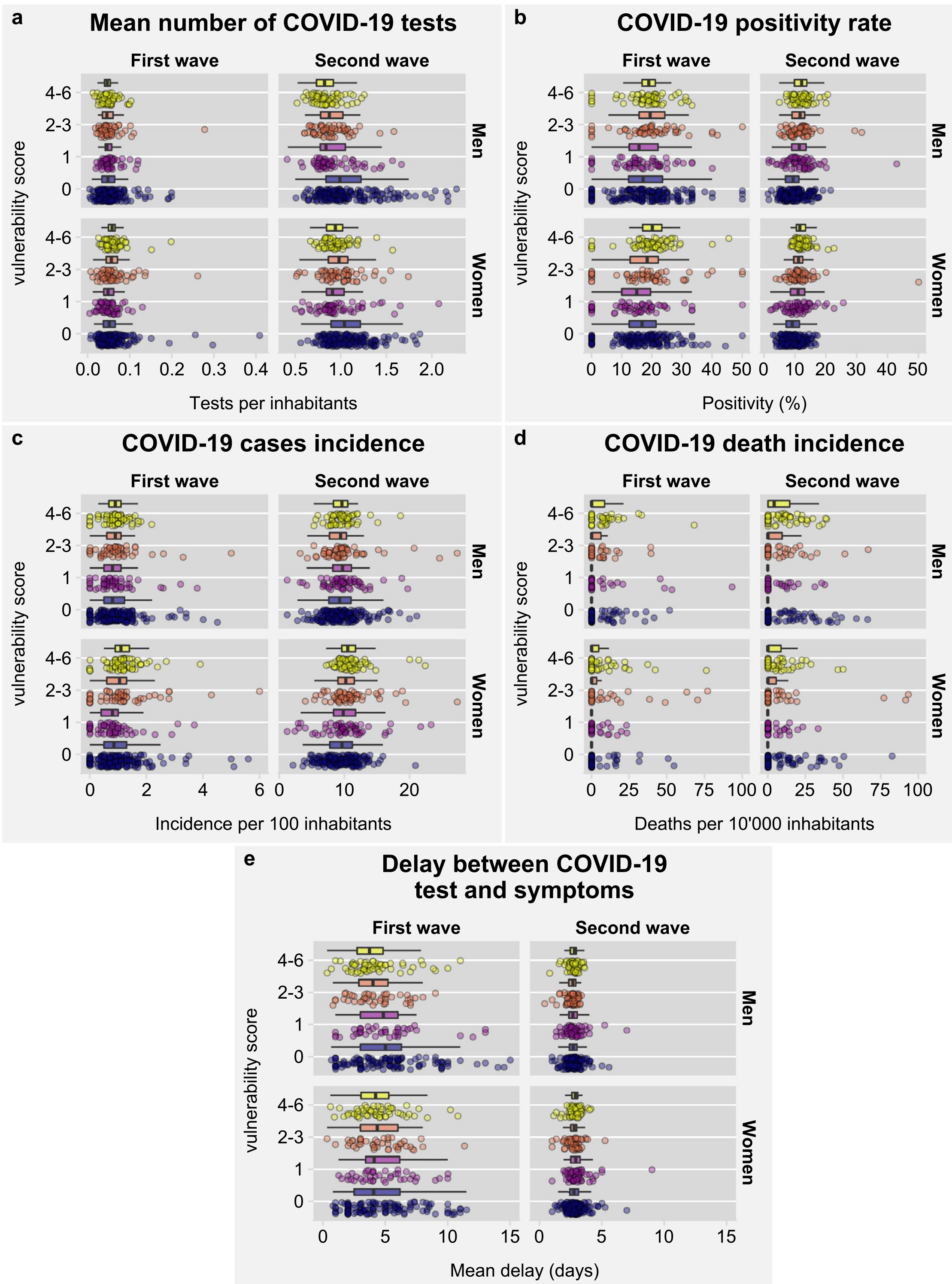

Figure 3. Mean number of tests per person (panel **a**), positivity rate (in percent, panel **b**), incidence of COVID-19 cases (number of cases per 100 inhabitants, panel **c**), incidence of COVID-19 deaths (number of deaths per 10'000 inhabitants, panel **d**) and mean delay between COVID-19 symptoms and test (in days, panel **e**) for each of the 368 neighbourhood considered (points), stratified by gender, time period, and vulnerability score.

rate. These results are consistent with previous findings[2,5,18,20,21] and confirm the recent observation of the inverse care law in Switzerland during the pandemic[5]: deprived neighbourhoods have less access to healthcare while being more at risk of infection and of severe disease.

The stratification by gender and epidemic waves exposes that this effect was modulated by the epidemic activity and the subsequent changes of public health policies, and differed for men and women. The lower access to tests for people living in poor socio-economic neighbourhoods was only observed during the second wave and went along an increased positivity rate for deprived neighbourhoods. During the first wave, women from poor neighbourhoods were more likely to be tested than those from wealthy neighbourhoods, and men from poor neighbourhoods were on average tested more rapidly than men from rich neighbourhoods. Finally, the association between socio-economic vulnerability and COVID-19 death incidence was only observed during the first wave and was stronger amongst women. We will here provide some potential hypotheses that could explain these results.

These stratified results must be analysed knowing that the two pandemic waves had a different context in terms of policies and testing capacities. During the first wave, the number of available tests was low and the population was under-tested. Priority was given to symptomatic cases, and during the shortage of reactants, to people with risk factors and to health care workers. Furthermore, a lockdown was implemented on March 26, then lifted on April 27, 2020, and was not re-implemented afterward. During the second wave, few restrictions were implemented, but the contact tracing of close contacts of persons infected by SARS-CoV-2 was systematised, leading to a 14-day quarantine.

The lower access to testing capacities of people living in vulnerable neighbourhoods probably finds its root in their occupational settings, the social distribution of which is structurally gendered.[35] Jobs typically require a lower level of qualifications, are more likely to be manual for men, and tend to be public-facing for women (care, nursing, and health). During the first wave, such workers represented the large majority of the essential workers that were not locked down.[36] As a consequence, they had higher access to testing during this period of restricted testing capacities, as illustrated by the shorter delay between symptoms and tests for men, or by the higher number of tests for women from vulnerable neighbourhoods. For these women, this came also with a higher incidence, because the people working in the nursing, home care services, and healthcare sectors were more exposed to the virus, as shown in Geneva by a previous study of SARS-CoV-2 antibodies prevalence[36] and in other countries as well.[37,38] During the second wave, the same occupational settings had the opposite effect. The tests became widely available, and the lower ability to work distantly for people from vulnerable neighbourhoods exerted downward pressure on their access to COVID-19 tests. Indeed, testing positive implied being forced to stop working for 14 days and caused co-workers to quarantine. The economic cost of such measures may have caused implicit or explicit discouragements to be tested, explaining the lower testing incidence amongst men from vulnerable neighbourhoods during the second wave. This was less the case for women, who have professional activities that are more public-facing, where testing was still recommended or even compulsory. On the other hand, this higher contact with the public resulted in a higher exposure to SARS-CoV-2 and thus an association between positivity and vulnerability similar to those of men.

The association between the incidence of COVID-19 deaths and socio-economic vulnerability could be the result of multiple factors. Air pollution could be one, as it seems to increase COVID-19 mortality[39] and has been shown to higher in areas with lower economic position.[40] Another factor could be the higher prevalence of COVID-19 risk factors associated with COVID-19 severity and mortality[41] amongst deprived populations.[42] These comorbidities have a higher incidence amongst men (e.g., obesity,[43] comorbidities,[44] chronic diseases or other main COVID-19 risk factors[45,46]), explaining their overall higher incidence of COVID-19 deaths. Biological factors, such as the role of oestrogens in the modulation of the ACE2[47] expression and regulation,[48] could also play a role. But the higher association between these comorbidities and the socio-economic vulnerability for women[42] could explain the observed stronger link between their COVID-19 death incidence and socio-economic vulnerability.

The lack of significant association between COVID-19 deaths and vulnerability during the second wave stemmed mainly from an increase in the death incidence amongst non-vulnerable populations (from a mean incidence of 230 per million inhabitants during the first wave to 554 per million inhabitants during the second wave). Indeed, the second wave of COVID-19 in Geneva was strong, and the city had one of the highest COVID-19 cases per inhabitant in Europe during this period. As a result, in such a high transmission context, the population was probably more equally affected across the social strata.

The use of a register representative of all reported tests on a regional level primarily serving operational needs with the aim of contacting all COVID-19 cases is a solid asset to this study, as it reduced the risk of selection bias affecting many COVID-19 studies. The use of an official index based on data from 2020 to identify socio-economic vulnerability is also a strength, as these data are contemporary to the pandemic. Finally, the low percentage of missing data, especially of geocoded addresses, combined with the multiple imputation approach, strengthens our results.

Despite these strengths, ARGOS database has been influenced by the testing policy. Individuals without risk factors for COVID-19 and those younger than 65 years were underrepresented in the database during the first wave. Furthermore, considering socio-economical vulnerability based only on geographically averaged variables can be seen as a limitation of our study, preventing us from studying individual aspects of the vulnerability. It furthermore does not incorporate other important aspects of social vulnerability, such as legal status, ethnicity, or working conditions.

People living in neighbourhoods with disadvantaged socio-economic conditions were more affected by COVID-19 than people living in wealthy environments in two ways: they tended to be more exposed to the disease and more at risk of severe disease and to have lower access to testing. As the association between socio-economic conditions and COVID-19 was in part driven by people's occupational settings and living conditions, it can be modulated by economic and health policies but also by gender.

Although men have a global higher incidence of death, the difference between the two sides of the social ladder is greater for women. The difference in access to tests between wealthy and poor neighbourhoods can be hidden by global restrictions of testing capacities or by strong political measures such as lockdown, or on the contrary enhanced by quarantine or isolation measures which affect workers selectively depending on their ability to work remotely. Therefore, the effect of neighbourhood socio-economic condition on access to healthcare must be considered in the light of the social and health policies and at the intersection with gender. Thus, although public health policies are supposed to target populations and not individuals, this study highlights the need to tailor policies for specific groups.

Contributors

Denis Mongin performed the data curation and the analysis, created the data visualisation, designed the article and wrote the first draft; Stéphane Cullati participated to the literature review, participated to the result interpretation and revised critically the article; Michelle Kelly-Irving participated to the result interpretation and revised critically the article, Maevane Rosselet participated to the result interpretation and revised critically the article, Simon Regard participated in the study design and revised critically the article, Delphine S. Courvoisier acquired the financial support for the project, conceptualised the analysis, participated in the data interpretation and to the article design, and revised critically the article. Denis Mongin, Simon Regard and Delphine Courvoisier had full access to the dataset. Denis Mongin and Delphine Courvoisier verified the data. All authors were responsible for the decision to submit for publication.

Data sharing statement

The de-identified database underlying this article will be shared on reasonable request using the form (https://edc.hcuge.ch/surveys/?s=TLT9EHE93C).

Declaration of interests

We declare no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.eclinm.2022.101352.

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