Stockholm Research Reports in Demography | no 2020:31

Residential Context and COVID-19 Mortality among the Elderly in Stockholm:

A population-based, observational study

Maria Brandén, Siddartha Aradhya, Martin Kolk, Juho Härkönen, Sven Drefahl, Bo Malmberg, Mikael Rostila, Agneta Cederström, Gunnar Andersson and Eleonora Mussino

ISSN 2002-617X | Department of Sociology

Stockholm University
Demography Unit

Residential Context and COVID-19 Mortality among the Elderly in Stockholm:
A population-based, observational study

Maria Brandén[1,2], Siddartha Aradhya[1], Martin Kolk[1,3], Juho Härkönen[1,4], Sven Drefahl[1], Bo Malmberg[5], Mikael Rostila[6,7], Agneta Cederström[6,7], Gunnar Andersson[1], Eleonora Mussino[1]

[1] Stockholm University Demography Unit; [2] Institute for Analytical Sociology; [3] Institute for Future studies; [4] Department of Political and Social Sciences, European University Institute; [5] Department of Human Geography; [6] Department of Public Health Sciences; [7] Centre for Health Equity Studies (CHESS)

Pre-print Abstract:

Background: Housing characteristics and neighbourhood context are considered risk factors for COVID-19 mortality among the elderly. This study is the first to examine how individual-level housing and neighbourhood characteristics are associated with old-age COVID-19 mortality.

Methods: We perform Cox proportional hazards regression for the risk of dying from COVID-19 (N=1,299) and from all other causes (N=2,302) in all individuals aged 70 and above living in the Stockholm region (N=274,542).

Findings: In fully adjusted models, household and neighbourhood characteristics are independently associated with COVID-19 mortality among the elderly. Compared to living in only-old households, living with someone of working age is associated with elevated COVID-19 mortality (HR = 1.6; 95% CI = 1.3-2.0). Living in a care home is associated with a 4-fold (HR = 4.1; 95% CI = 3.5-4.9) risk of COVID-19 mortality compared to living in independent housing. Living in neighbourhoods with the highest population density was associated with higher COVID-19 mortality (HR = 1.6; 95% CI = 1.1-2.4) compared to living in the least densely populated neighbourhoods.

Interpretation: The close exposure to working-age individuals -- be it in the form of care workers, household members, or neighbours -- can have detrimental effects on elderly people's ability to survive the COVID-19 pandemic. These factors should be taken into account when developing strategies to protect this group.

Funding: The Swedish Research Council for Health, Working Life and Welfare (FORTE), grant 2016-07115. The Swedish Foundation for Humanities and Social Sciences (Riksbankens Jubileumsfond), grant M18-0214:1.

Keywords: SARS-CoV-2; register data; multigenerational households; neighbourhood

Stockholm Research Reports in Demography 2020:31

ISSN 2002-617X

Introduction

Older individuals are overrepresented among deaths due to COVID-19[1–4], raising questions of how to best mitigate patterns of social contact as the pandemic progresses[5–8]. Researchers have underlined the importance of living arrangements and household composition, such as care homes, crowded housing and age-mixed households, as well as social contacts outside the household for understanding the spread of SARS-CoV-2[1–6,9–12]. Living arrangements relate to elderly people's care needs, which in turn shape their contacts with carers from within or outside the household. In addition to living arrangements, elderly people's risk of infection can be shaped by their broader neighbourhood environment. Residential clustering of infections has received wide attention in the extant studies[10,12]. In attempting to understand the structural features responsible for differences in the spread of the virus across neighbourhoods, early hypotheses pointed to population density as an important contributor, but the evidence has been mixed[9].

A major limitation of previous research on the associations between living arrangements, neighbourhood characteristics, and COVID-19 mortality has been the reliance on aggregated data, unadjusted for differences by age and other individual-level risk factors. Because how and where elderly people live is partly determined by their socio-demographic characteristics and health, drawing individual-level conclusions based on aggregated data can lead to biased conclusions on the importance of living arrangements and neighbourhoods in COVID-19 mortality.

Focusing on the elderly population (70 years and above) in Stockholm county, Sweden, this is the first study to use individual-level data to examine how living arrangements and neighbourhood characteristics are associated with COVID-19 mortality, after adjusting for age and other socio-demographic risk factors[3]. We use administrative data to analyze how mortality from COVID-19 is related to the elderly population's living arrangements and neighbourhood characteristics[3]. By comparing these results to patterns in mortality from all other causes of death, we can gauge which risk factors are specific to mortality from COVID-19, and which ones mainly reflect selection of frail individuals into certain types of living arrangements or neighbourhoods.

Methods

Data sources and study population

We use the Swedish cause of death register updated up until May 8, 2020, which enables us to distinguish between recorded COVID-19 mortality and mortality from other causes of death[13]. This information is linked to administrative population register individual-level data on a wide range of socio-economic, demographic, and residential characteristics of all individuals living in the capital region of Sweden in December 2019. We exclude all individuals who were below age 70 at the beginning of our observation period, which is March 5, 2020 onwards (the date of the first death from COVID-19 in Sweden). We can identify the apartment or house in which each individual was registered in December 2019, which we use to measure household size and household age composition as well as to determine the neighbourhood of the abode. We also have information about whether an individual was registered as living in a private household or care home, and can distinguish between single-family and multi-family housing. We can therefore provide the first representative picture on how the risk of COVID-19 mortality differs by household

arrangement. The number of individuals in our data is 274,542 (see Figure S1 for a flowchart of exclusion of cases).

Measures

Outcome variable

We use data on all deaths reported between March 5, 2020 (the date of the first confirmed death by COVID-19 in Sweden) and May 8, 2020, and whether each death was associated with COVID-19. The data on deaths contain all individuals who lived in Stockholm county, and had been resident in Sweden for at least two years. The data on deaths were collected by the Swedish National Board of Health and Welfare, the agency responsible for the cause of death register[14]. In the study population, 3,367 individuals died during the studied period, 1,299 of these deaths are reported as COVID-19 deaths. Of these deaths, COVID-19 was identified as the underlying cause of death in 1,250 cases (emergency ICD code U07.1, U07.2 or B343). In the remaining 49 cases, ICD emergency codes U07.1, U07.2 or B343 were listed as contributing causes of death but not the underlying cause of death. The confirmed COVID-19 deaths accounted for a 70-90% excess mortality in Stockholm during the weeks covered by our data[15]. During the COVID-19 outbreak in Sweden, deaths have to a large extent been concentrated in the Stockholm region. Our data capture the great majority of excess deaths in Stockholm as reported by mid-June 2020 (See Figure S2).

Individual and household level variables

All covariates in our study are time-constant and either measured at the end of 2019 (all variables at the household and neighbourhood level) or 2018 (highest education attained, individual net income). Information on age, sex, and country of birth stem from the Total Population Register. Country of birth is categorized into (i) Sweden (ii) high-income countries (HIC) (iii) low- and middle-income countries from the Middle-East and North-Africa (LMIC MENA), and (iv) other low- and middle-income countries (LMIC other). Income is derived from Swedish taxation registers and categorized into tertiles based on the full adult population of Sweden. Education data from Swedish educational registers are categorized into primary schooling, secondary schooling, post-secondary education, and missing information. From Swedish dwelling registers we access information on housing type, size of the dwelling and a unique dwelling code which enables us to link individuals who live together in a household, and to assess the number of household members and their characteristics. By combining these sets of information, we create measures capturing (1) the number of individuals per square metre in the household, and (2) a composite measure of age structure that distinguishes between (i) living in a household consisting of only one individual (the ego, who is above 70), (ii) living only with one or more individuals aged above 66 (this mostly includes the ego's partner), (iii) living with at least one individual below 66, (iv) living with both at least one individual below 66 and at least one child below age 16, (v) a small group that comprises all other living arrangements. We also create a measure for (3) the type of housing, which distinguishes between single-family housing, multi-family housing, and care homes.

All register information, including causes of deaths, are seamlessly linked through personal identity numbers that are unique to each person with legal residence in Sweden.

Neighbourhood level variables

Neighbourhood characteristics are measured at two levels of aggregation. Our first measure is the incidence proportion in a borough, defined as the number of confirmed COVID-19

infections by April 14, 2020 per 10,000 inhabitants. The 39 boroughs in our data consists of 14 city districts (Stadsdel) in the City of Stockholm (average population size 69,300) and the remaining 25 municipalities of Stockholm county. The caseload data came from Smittskydd Stockholm (See Table S1) and the population size data refer to the end of 2019. Our second measure is neighbourhood population density (number of individuals per square kilometer) which is computed for the 1,313 demographic statistical areas, DeSO, constructed by Statistics Sweden, with an average population of 1,800. See Figure S3 for the borders of boroughs and neighbourhoods within Stockholm City and Figure S4 for the equivalent for the full Stockholm region.

Statistical analyses

All analyses were conducted in Stata 16.0. We conducted Cox regressions for dying from COVID-19 and from all other causes, respectively. Individuals had two ways to exit the study: (1) by dying between March 5, 2020 and May 8, 2020, or (2) being alive on May 8, 2020. We ran two separate regressions estimating (1) the cause-specific hazard of dying from COVID-19, right-censoring all individuals that die from other causes, and (2) the cause-specific hazard of dying from other causes than COVID-19, right-censoring at death from COVID-19[16,17].

Role of the Funding Source

Funders had no role in study design, data collection, data analysis, data interpretation, writing of the report, or the decision to submit for publication. The corresponding author had full access to all of the data and the final responsibility to submit for publication.

Results

Table 1 describes our study population and the incidence rates of COVID-19 death for all our covariates. Living in a crowded household is associated with higher COVID-19 mortality among the elderly, with the highest incidence rate (IR) of 65 deaths per 1,000 person years for those living in the most crowded households, compared to an incidence rate of 19 among those living in the least crowded households. In terms of the age structure of the household, the lowest rate of COVID-19 mortality was found among individuals co-residing with someone older than 66 years (IR 17), followed by those co-residing with someone in working age (IR 29) and those living alone (IR 38). Housing type is clearly associated with COVID-19 mortality where individuals living in multi-family housing (IR 23) have higher mortality than those living in single-family housing (IR 14) whereas the highest mortality (IR 207) is found among individuals living in care homes. Almost one third (29%) of all deaths occurred in people registered in elderly care homes.

We found differences in mortality by the number of confirmed COVID-19 infections in the borough. Individuals who lived in the most affected boroughs had an incidence rate of 35, compared to 6 in the least affected boroughs. The population density in a neighbourhood had similar associations, with an incidence rate of 35 in the most densely populated neighbourhoods, compared to 10 in the more sparsely populated neighbourhoods.

With respect to SES we found that individuals with low income, low education and foreign-born were more adversely affected by the COVID-19 pandemic.

Table 1. Distribution of characteristics and incidence of death from COVID-19 among individuals aged 70 and above in Stockholm.

	N at March 5	%	N dead from COVID-19	Exposure time in years	COVID-19 deaths per 1000 years
SqM per individual in household					
0-	7,850	2·9	88	1,359	65
20-	19,322	7·0	183	3,349	55
30-	43,269	15·8	323	7,511	43
40-	88,984	32·4	320	15,521	21
60-	114,174	41·6	383	19,910	19
Missing	943	0·3	[less than 5]	165	12
Age structure of household					
1 person household· 70+	110,745	40·3	737	19,243	38
Co-residing with someone older than 66	124,921	45·5	361	21,799	17
Co-residing with someone aged 66 or younger	32,975	12·0	168	5,746	29
Co-residing with someone aged 66 or younger· and child aged 16 or younger	5,491	2·0	32	957	33
Other	410	0·1	[less than 5]	72	14
Housing					
Multi-family housing	173,052	63·0	700	30,162	23
Single-family housing	90,571	33·0	219	15,814	14
Care home	10,919	4·0	380	1,840	207
Incidence proportion of COVID-19 per 10·000 inhabitants in borough					
0-	20,571	7·5	23	3590	6
10-	48,178	17·5	217	8396	26
15-	121,951	44·4	546	21,243	26
20-	83,842	30·5	513	14,587	35
Individuals per SqKm in neighborhood					
0-	19,219	7·0	34	3,356	10
150-	17,708	6·5	62	3,086	20
500-	60,092	21·9	242	10,476	23
2000-	68,403	24·9	304	11,908	26
5000-	109,120	39·7	657	18,989	35
Country of birth					
Sweden	217,661	79·3	927	37,915	24

HIC	37,515	13·7	210	6,532	32
LMIC MENA	7,530	2·7	83	1,308	63
LMIC other	11,836	4·3	79	2,060	38
Educational level					
Primary	61,993	22·6	415	10,767	39
Secondary	106,840	38·9	504	18,610	27
Post-secondary	99,755	36·3	308	17,407	18
Missing	5,954	2·2	72	1,032	70
Individual disposable income					
Lowest tertile	115,512	42·1	708	20,085	35
Mid tertile	98,359	35·8	438	17,135	26
Highest tertile	60,671	22·1	153	10,596	14
Sex					
Man	121,232	44·2	660	21,101	31
Woman	153,310	55·8	639	26,714	24
TOTAL	274,542	100·0	1,299	47,816	27

Source: Own calculations based on Swedish register data

Figure 1 shows the results from the fully adjusted Cox regression models of COVID-19 mortality (blue) and mortality from all other causes of death (red). Full regression models from Figure 1 can be found in Table S2. Housing density is associated with COVID-19 mortality and mortality due to other causes of death, with similarly higher death rates in more densely populated dwellings. Compared to individuals co-residing with someone older than 66, COVID-19 mortality is higher among individuals living alone (HR = 1.6; 95% CI = 1.4-1.9) and among individuals living with someone of working age (HR = 1.6; 95% CI = 1.3-2.0). The latter effect is notably higher than the corresponding HR for mortality from other causes of death (HR = 1.0; 95% CI = 0.9-1.2), whereas for the former, confidence intervals overlap (HR = 1.4; 95% CI = 1.2-1.6). Individuals who were also co-residing with a child had COVID-19 mortality rates similar to those only co-residing with at least one working-age individual (HR = 1.4; 95% CI = 0.9-2.1). In the fully adjusted models, there is no difference in COVID-19 mortality among those living in single-family housing and those living in multi-family housing. Elderly care residents had four times as high COVID-19 mortality, compared to individuals living in single- or multi-family housing, (HR = 4.1; 95% CI = 3.5-4.9). Elderly care residents also had clearly elevated mortality from other causes of death, but the corresponding HR (2.6; 95% CI = 2.3-3.0) remained lower than that for COVID-19 mortality.

Individuals living in boroughs with less than 10 confirmed COVID-19 cases per 10,000 inhabitants had significantly lower mortality from the disease than those in areas with higher caseloads. COVID-19 mortality was elevated by a factor 4 in areas with over 20 confirmed cases per 10,000 inhabitants (HR = 4.2; 95% CI: 2.7-6.5). In these residential areas, mortality from all other causes was statistically significantly higher as well (HR = 1.3; 95% CI: 1.1-1.6). We also found a positive association with population density but only neighbourhoods with the highest population density had statistically significantly elevated mortality from COVID-19 (HR = 1.6; 95% CI: 1.1-2.4). We found no statistically significant association between population density and other causes of death during our observation period.

Figure 1. Hazard ratios of COVID-19 mortality and mortality from other causes among individuals aged 70 and above in Stockholm county. Cox regressions. All models control for individual age, sex, education, income, and country of birth. Logged x-axis.

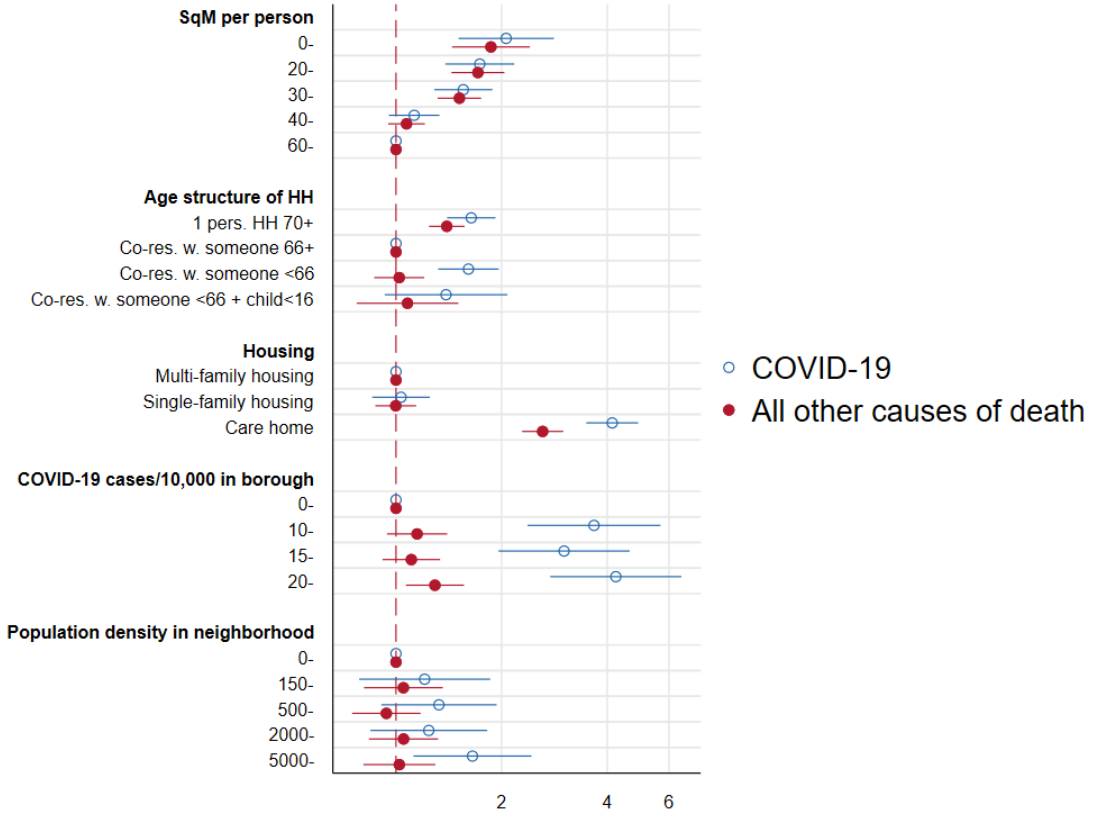
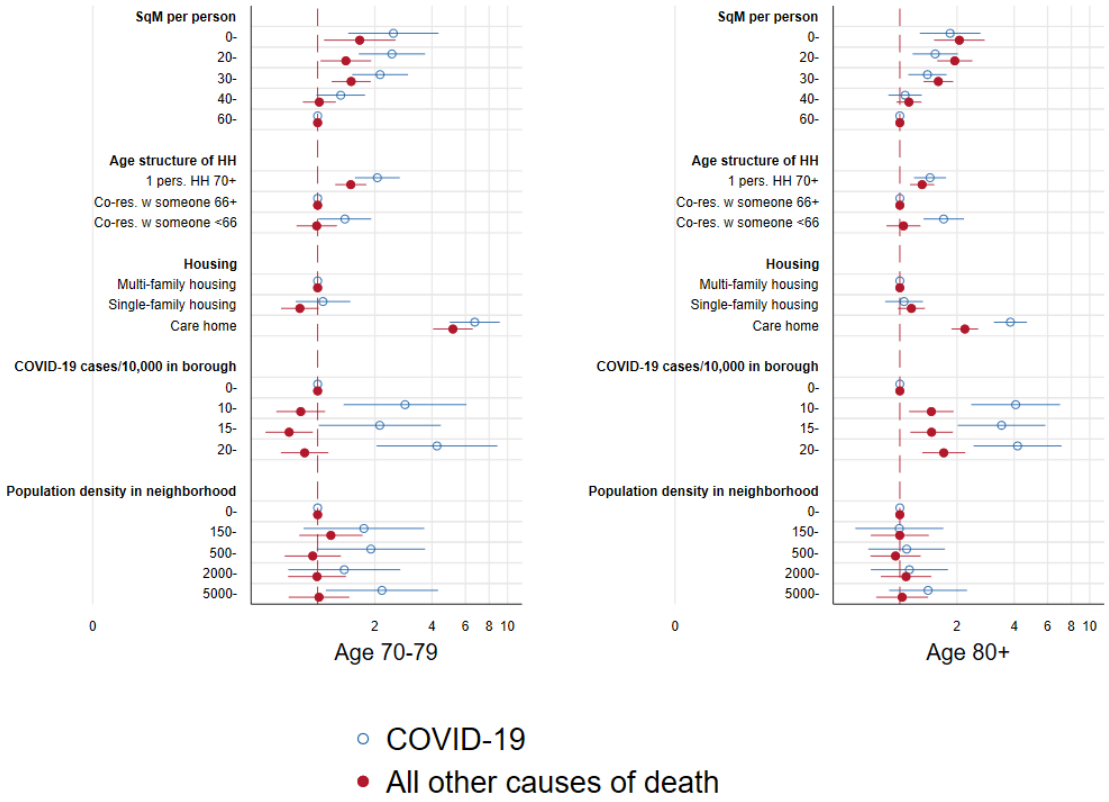


Figure 2 presents results from Cox regressions on COVID-19 mortality stratified by age group (see also Table S3). To gain statistical power we collapsed the categories of co-residing with someone in working age with or without children. The largest differences between the two age groups are in the association between living in a care home and COVID-19 mortality. Individuals aged 70-79 have a higher excess death rate when living in a care home (HR = 6.7; 95% CI: 5.0-9.1) compared to individuals aged 80 and above (HR = 3.8; 95% CI: 3.1-4.7). Individuals aged 70-79 who live in a care home also have elevated mortality from other causes than COVID-19 (HR = 5.2; 95% CI: 4.0-6.6). In terms of living with someone in working age, for the younger elderly, confidence intervals of COVID-19 mortality (HR = 1.4; 95% CI: 1.0-1.9) overlap with those of mortality from other causes (HR = 1.0; 95% CI: 0.8-1.3), whereas among individuals aged 80 and above coresiding with someone in working age is only associated with excess mortality from COVID-19 (HR = 1.7; 95% CI: 1.3-2.2), not with other-cause mortality (HR = 1.0; 95% CI: 0.9-1.3).

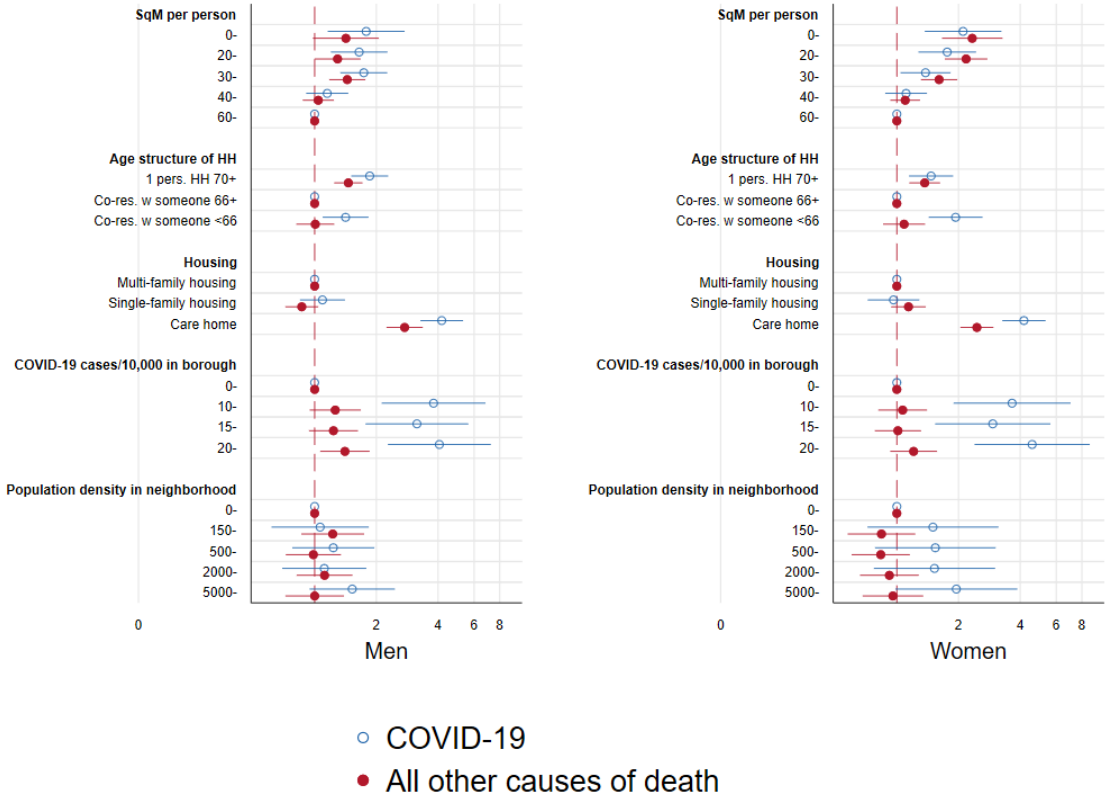
We found no differential effects by age group in the association between the caseload of COVID-19 in one's borough and COVID-19 mortality. However, for mortality from other causes, we found a 70 percent increase in mortality among the oldest-old individuals who lived in an area with more than 20 confirmed cases compared to the least affected areas (HR = 1.7; 95% CI: 1.3-2.2).

Figure 2. Hazard ratios of COVID-19 mortality and mortality from other causes among individuals aged 70 and above in Stockholm county, by age group 70-79 and 80+, respectively. Cox regressions. All models control for individual age, sex, education, income, and country of birth. Logged x-axis.



Finally, we present separate models for women and men in Figure 3 (see also Table S4). The main difference between elderly women and men is that females are more adversely affected in COVID-19 mortality from living with an individual in working age (HR = 1.9; 95% CI: 1.4-2.6), whereas for men the confidence interval overlaps with that of all cause mortality (HR = 1.4; 95% CI: 1.1-1.8). We find something similar for the impact of elderly care, where the confidence intervals overlap for men, but not for women. Overall, there seems to be few interactions between gender and our independent covariates in COVID-19 mortality.

Figure 3. Hazard ratios of COVID-19 mortality and mortality from other causes among individuals aged 70 and above in Stockholm county, by sex. Cox regressions. All models control for individual age, education, income, and country of birth. Logged x-axis.



Discussion

The main finding from this study is that living arrangements and neighbourhood characteristics independently predict mortality from COVID-19 among people aged 70 and above, after adjusting for age, sex, education, income, and country of birth. Research on the spread of SARS-CoV-2 has pointed to abodes as important sites for transmission of the virus[10,12,18]. Consequently, housing type and household composition have been suggested as correlates of contracting the virus as well as of differences in mortality between regions and countries[5,19]. The results from our fully adjusted models which compared mortality from COVID-19 and other causes of death point to two specific living arrangements as risk factors for COVID-19 mortality.

First, we found that residence in age-mixed households was associated with higher COVID-19 mortality, in line with earlier suggestions of higher risk of SARS-CoV-2 infection in these households through their indirect exposure to outside social milieus[1]. This association was more apparent among women than among men. Multigenerational living may thus have contributed to COVID-19 mortality in countries where it is common[20]. We found no additional impact of co-residing with children, even though Swedish schools have remained open for children below age 16 throughout the pandemic. This result does not support hypotheses of children as major transmitters of SARS-CoV-2[18,21].

Second, our findings confirm the high COVID-19 mortality in care homes. The excess COVID-19 mortality in these institutions was strongly attenuated in the fully adjusted model but remained large. It was higher than the excess mortality from other causes, and our results are closely in line with official reports on excess all-cause mortality in care homes during the period covered in our study[22]. Implementing strict guidelines for visitation and providing the necessary protective equipment for care home employees are strategies that may improve conditions (in Sweden, these measures were not introduced immediately). At the same time, the strong attenuation of excess mortality from COVID-19 in the fully adjusted model together with high excess mortality of care home residents from other causes suggest that COVID-19 deaths in care homes were in large part due to their high concentration of older and more frail individuals[23]. These results point to other factors than the care home context as main drivers of COVID-19 mortality in these settings.

In terms of other living arrangements, living alone or in more crowded housing were associated with similarly higher mortality from COVID-19 and other causes of death[5,16] suggesting no additional risk from COVID-19, but rather unobserved frailty associated with elderly in these living arrangements[24]. Neither could we find any difference in COVID-19 mortality rates between elderly people living in multi-family and single-family housing. Thus, we do not find any indication that elevators, corridors and other common spaces in multiple-unit housing blocks have functioned as important sources of SARS-CoV-2 infections.

The importance of neighbourhood transmission of SARS-COV-2 has been contested[9,25]; however, previous studies have not examined the role of neighbourhood exposure at the individual-level, and may thus be confounded. We used two neighbourhood-level measures to assess how COVID-19 mortality among the elderly relates to neighbourhood characteristics; these measures could be seen as proxies for the potential of interaction with neighbours (neighbourhood density) and the risk associated with the interaction with neighbours (confirmed cases). We find stronger support for the latter. Compared to boroughs with no or few confirmed cases (0-9 per 10,000 residents), elderly living in boroughs with higher caseloads had strongly elevated death rates from COVID-19 but not from other causes. This was a threshold effect, with no gradual elevation in COVID-19 death rates with successively increasing borough-level caseloads. Additionally, we found indications of increasing COVID-19 death rates in more dense neighbourhoods, but the estimates were imprecise. All this suggests that neighbourhood transmission matters, even though the 70+ population to a large extent have been self-isolating.

Population register data hold many advantages, however, they capture de jure rather than de facto characteristics of individuals. Our data therefore likely underestimates the number of individuals living in elderly care, since the frailest old individuals sometimes are not able to register their move into a care home before passing away or because we misclassify the elderly who moved into care homes in 2020. Also, mortality from other causes that we use as comparison is occurring in a setting where COVID-19 exists, and thus may capture indirect COVID-19 effects (collateral deaths). For instance, the fear of contracting COVID-19 may impact the care seeking of individuals, which may in turn increase the risk of other causes of death[26]. As such, by only studying confirmed COVID-19 deaths, we may underestimate the true mortality effect of the pandemic. Also, although the Swedish data on COVID-19 deaths is considered accurate, we cannot rule out some misclassification of COVID-19 deaths. Finally, the measure of the number of positive COVID-19 cases in boroughs suffer from three drawbacks. First, it only captured individuals with symptoms severe enough to entail testing, meaning that it underestimates the number of actual cases. Secondly, boroughs are

large, and individuals in the same borough are not necessarily interacting. Accessing data on reported cases on a finer granularity, both in terms of symptoms and spatial resolution, would be useful to more accurately assess how neighbourhood transmission affects COVID-19 mortality. Third, we cannot rule out confounding by unobserved neighbourhood characteristics.

Concluding, our results are the first to empirically test the importance of residential context on fatalities from COVID-19 among the elderly, whilst adjusting for potential confounders using individual level data and comparing with mortality from other causes. The conclusion to draw from our results is that in a context with a wide spread of SARS-CoV-2, the close exposure to working-age individuals -- be it in the form of care workers, household members, or neighbours -- can have detrimental effects on elderly individuals' ability to survive the pandemic. Strategies to protect individuals in care homes, in densely populated areas, and in families with multigenerational living arrangements may increase survival among the elderly population.

Author contribution statement

M.B. jointly conceived the study with M.K., S.A., E.M., S.D. and B.M. B.M., G.A., M.B., M.R. and A.C. provided the data. M.B. analyzed the data. B.M. created maps. S.A., E.M., M.K., J.H., M.B. and S.D wrote the manuscript; G.A. edited the manuscript. E.M. coordinated the project. G.A. supervised the project. All authors read and approved the final version of the manuscript.

Data availability statement and ethical considerations

This study is produced under the Swedish Statistics Act, where privacy concerns restrict the availability of register data for research. Aggregated data can be made available by the authors, conditional on ethical vetting. The authors access the individual-level data through Statistics Sweden's micro-online access system MONA. The analyses have been approved by the Swedish Ethical Review Authority, Dnr 2020-02199.

References

1 Esteve A, Permanyer I, Boertien D, Vaupel JW. National age and co-residence patterns shape covid-19 vulnerability. 2020. DOI:10.1101/2020.05.13.20100289.

2 Giangreco G. Case fatality rate analysis of Italian COVID-19 outbreak. Journal of Medical Virology 2020; 92: 919–23.

3 Drefahl S, Wallace M, Mussino E, et al. Socio-demographic risk factors of COVID-19 deaths in Sweden: A nationwide register study. Stockholm Research Reports in Demography Preprint 2020. DOI:10.17045/sthlmuni.12420347.v2.

4 Modig K, Ebeling M. EXCESS MORTALITY FROM COVID-19. WEEKLY EXCESS DEATH RATES BY AGE AND SEX FOR SWEDEN. 2020. https://doi.org/10.1101/2020.05.10.20096909.

5 Arpino B, Bordone V, Pasqualini M. Are intergenerational relationships responsible for more COVID-19 cases? A cautionary tale of available empirical evidence. SocArXiv 2020; published online May 6. DOI:https://doi.org/10.31235/osf.io/y8hpr.

6 Stokes JE, Patterson SE. Intergenerational Relationships, Family Caregiving Policy, and COVID-19 in the United States. Journal of Aging & Social Policy 2020; 32: 416–24.

7 Dowd JB, Andriano L, Brazel DM, et al. Demographic science aids in understanding the spread and fatality rates of COVID-19. PNAS 2020; 117: 9696–8.

8 Balbo N, Billari F, Melegaro A. The strength of family ties and COVID-19. Context 2020. https://contexts.org/blog/structural-shocks-and-extreme-exposures/#balbo (accessed June 10, 2020).

9 COVID-19 Cases in New York City, a Neighborhood-Level Analysis. The Stoop: NYU Furman Center Blog. 2020; published online April 10. https://furmancenter.org/thestoop/entry/covid-19-cases-in-new-york-city-a-neighborhood-level-analysis (accessed June 18, 2020).

10 Li W, Zhang B, Lu J, et al. Characteristics of Household Transmission of COVID-19. Clinical Infectious Diseases 2020; : ciaa450.

11 Jing Q-L, Liu M-J, Zhang Z-B, et al. Household secondary attack rate of COVID-19 and associated determinants in Guangzhou, China: a retrospective cohort study. The Lancet Infectious Diseases 2020; : S1473309920304710.

12 Wang Z, Ma W, Zheng X, Wu G, Zhang R. Household transmission of SARS-CoV-2. Journal of Infection 2020; 81: 179–82.

13 Brooke HL, Talbäck M, Hörnblad J, et al. The Swedish cause of death register. European journal of epidemiology 2017; 32: 765–73.

14 Beskrivning av datakällor för avlidna i covid-19. Socialstyrelsen, 2020 https://www.socialstyrelsen.se/globalassets/sharepoint-dokument/dokument-webb/statistik/rapportering-av-dodsfall.pdf.

15 Veckorapport om covid-19, vecka 23. Folkhälsomyndigheten, 2020 https://www.folkhalsomyndigheten.se/globalassets/statistik-uppfoljning/smittsamma-sjukdomar/veckorapporter-covid-19/2020/covid-19-veckorapport-vecka-23-final-v2.pdf.

16 Lau B, Cole SR, Gange SJ. Competing Risk Regression Models for Epidemiologic Data. American Journal of Epidemiology 2009; 170: 244–56.

17 Lunn M, McNeil D. Applying Cox Regression to Competing Risks. Biometrics 1995; 51: 524.

18 Prem K, Liu Y, Russell TW, et al. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study. The Lancet Public Health 2020; 5: e261–70.

19 Bayer C, Kuhn M. Intergenerational Ties and Case Fatality Rates: A Cross-Country Analysis. IZA Discussion Papers 13114 2020. http://ftp.iza.org/dp13114.pdf.

20 Padyab M, Reher D, Requena M, Sandström G. Going it alone in later life: a comparative analysis of elderly women in Sweden and Spain. Journal of Family Issues 2019; 40: 1038–64.

21 Ludvigsson JF. Children are unlikely to be the main drivers of the COVID-19 pandemic–a systematic review. Acta Paediatrica 2020.

22 Dödlighet bland äldre med särskilt boende eller hemtjänst, 2016–2020. Socialstyrelsen, 2020.

23 Schön P, Lagergren M, Kåreholt I. Rapid decrease in length of stay in institutional care for older people in Sweden between 2006 and 2012: results from a population-based study. Health & Social Care in the Community 2016; 24: 631–8.

24 Manzoli L, Villari P, Pirone GM, Boccia A. Marital status and mortality in the elderly: a systematic review and meta-analysis. Social science & medicine 2007; 64: 77–94.

25 Fang W, Wahba S. Urban Density Is Not an Enemy in the Coronavirus Fight: Evidence from China. 2020. https://blogs.worldbank.org/sustainablecities/urban-density-not-enemy-coronavirus-fight-evidence-china (accessed June 24, 2020).

26 Marijon E, Karam N, Jost D, et al. Out-of-hospital cardiac arrest during the COVID-19 pandemic in Paris, France: a population-based, observational study. The Lancet Public Health 2020; : S2468266720301171.

Supplemental material

Figure S1. Flowchart of exclusion of observations

Figure S2. Excess mortality in Stockholm by week, all-cause mortality

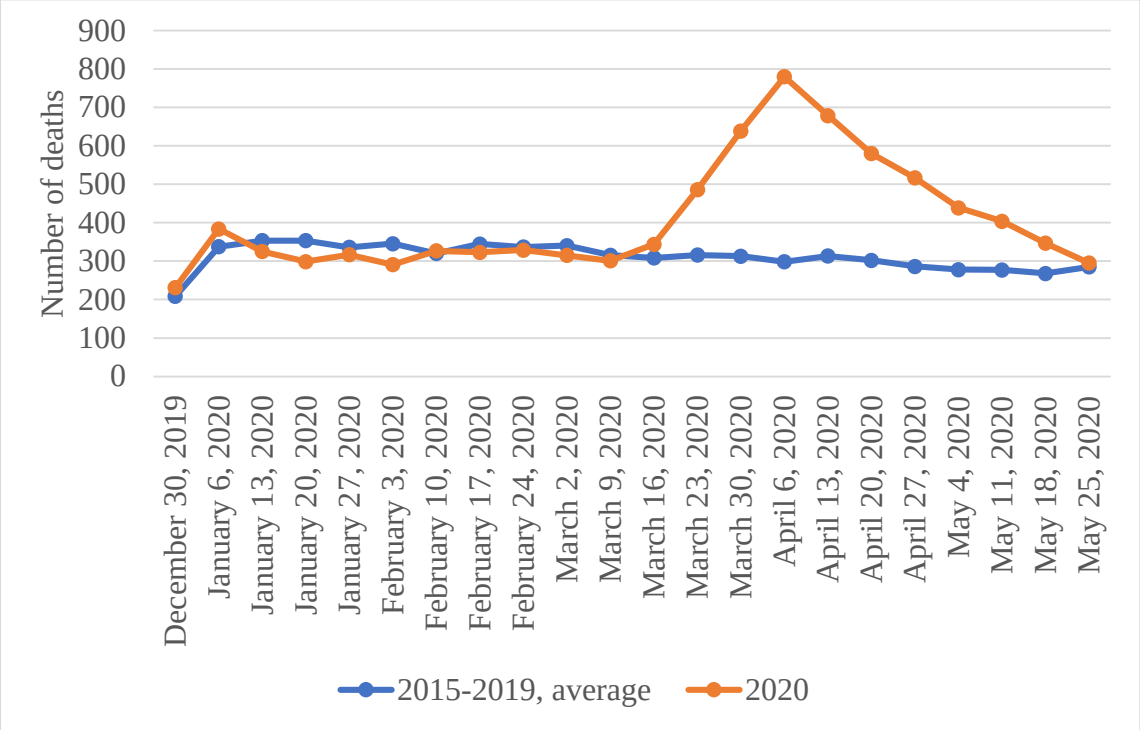


Figure S3. Overlay map of Boroughs (Stadsdelar), in red, on DeSO areas, black, for central parts of Stockholm County. Urban districts geometry is from Stockholm Region Assembly (http://tfatestweb.se/kartportalen/dataokarta.html). DeSO geometry is from Statistics Sweden.

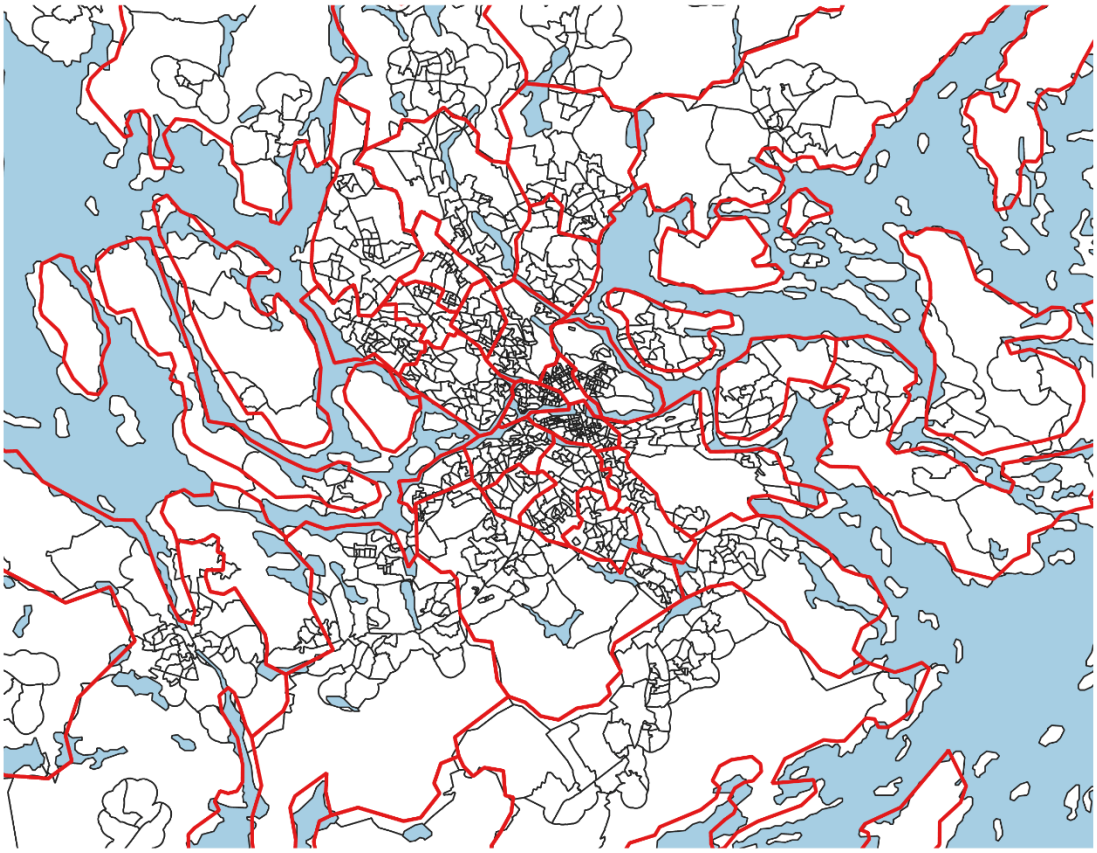


Figure S4. Overlay map of Boroughs (Stadsdelar), in red, on DeSO areas, black, for all of Stockholm County. Urban districts geometry is from Stockholm Region Assembly (http://tfatestweb.se/kartportalen/dataokarta.html). DeSO geometry is from Statistics Sweden.

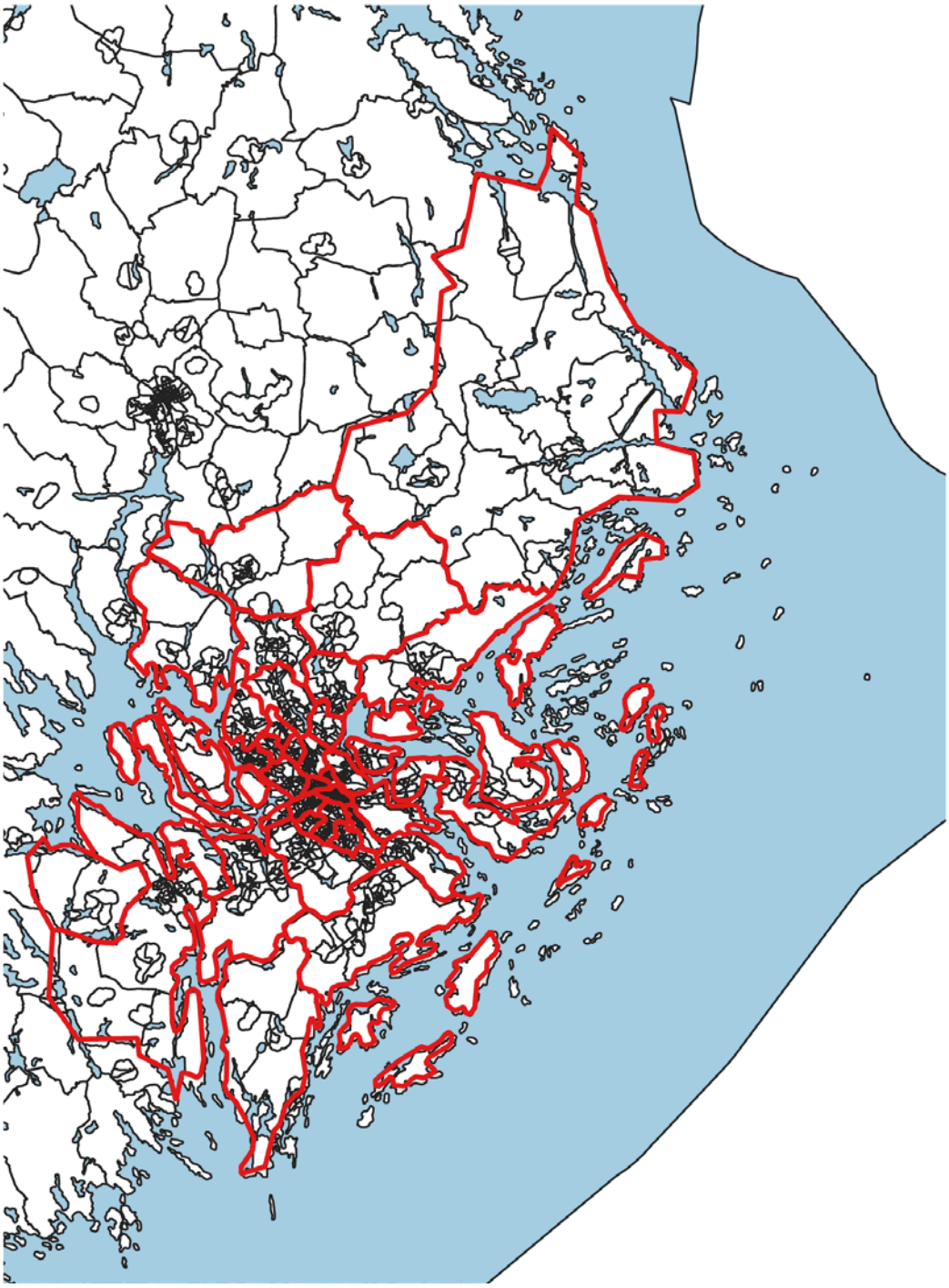


Table S1. Number of confirmed cases by borough, April 14, 2020

Borough	Cases by April 14	Cases by April 14, per 10,000 inhabitants
Botkyrka	177	19
Bromma	129	16
Danderyd	54	16
Ekerö	35	12
EnskedeÅrstaVantör	171	17
Farsta	106	18
Haninge	123	13
Huddinge	157	14
HägerstenLiljeholmen	126	14
HässelbyVällingby	151	20
Järfälla	164	20
Kungsholmen	107	15
Lidingö	92	19
Nacka	180	17
Norrmalm	169	21
Norrtälje	40	6
Nykvarn	15	14
Nynäshamn	17	6
RinkebyKista	295	58
Salem	25	15
Sigtuna	103	21
Skarpnäck	77	17
Skärholmen	99	26
Sollentuna	172	23
Solna	178	22
SpångaTensta	185	48
Sundbyberg	173	33
Södermalm	215	16
Södertälje	226	23
Tyresö	96	20
Täby	114	16
Upplands-Bro	41	14
Upplands Väsby	80	17
Vallentuna	24	7
Vaxholm	24	20
Värmdö	46	10
Älvsjö	69	22
Östermalm	138	18
Österåker	46	10

Note: data collected from https://vardgivarguiden.se/nyheter/2020/april/14-april-antal-personer-med-covid-19-per-kommunstadsdel/

Table S2. Hazard ratios of COVID-19 mortality and mortality from other causes among individuals aged 70 and above in Stockholm county. Cox regressions. All models control for age, sex, education, income, and country of birth.

	COVID-19			All other causes of death		
	b	min95	max95	b	min95	max95
SqM per individual in household						
0-	2·06	1·51	2·82	1·87	1·44	2·41
20-	1·73	1·38	2·17	1·71	1·44	2·04
30-	1·56	1·29	1·88	1·52	1·32	1·75
40-	1·13	0·95	1·33	1·07	0·95	1·21
60-	1·00	1·00	1·00	1·00	1·00	1·00
Missing	1·40	0·34	5·71	0·85	0·31	2·29
Age structure of household						
1 person household, 70+	1·64	1·40	1·92	1·40	1·24	1·57
Co-residing with someone older than 66	1·00	1·00	1·00	1·00	1·00	1·00
Co-residing with someone aged 66 or younger	1·61	1·32	1·96	1·02	0·87	1·20
Co-residing with someone aged 66 or younger, and child aged 16 or younger	1·39	0·93	2·08	1·08	0·77	1·51
Other	0·70	0·10	5·00	1·13	0·36	3·53
Housing						
Multi-family housing	1·00	1·00	1·00	1·00	1·00	1·00
Single-family housing	1·03	0·86	1·25	1·00	0·87	1·14
Care home	4·14	3·49	4·90	2·62	2·29	3·00
N confirmed cases per 10,000 inhabitants in borough						
0-	1·00	1·00	1·00	1·00	1·00	1·00
10-	3·67	2·37	5·68	1·15	0·94	1·40
15-	3·01	1·96	4·64	1·11	0·92	1·34
20-	4·24	2·75	6·51	1·29	1·07	1·56
Individuals per SqKm in neighborhood						
0-	1·00	1·00	1·00	1·00	1·00	1·00
150-	1·21	0·79	1·86	1·05	0·81	1·36
500-	1·33	0·91	1·94	0·94	0·75	1·18
2000-	1·24	0·85	1·82	1·05	0·84	1·32
5000-	1·65	1·12	2·43	1·02	0·81	1·29

Country of birth						
Sweden	1·00	1·00	1·00	1·00	1·00	1·00
HIC	1·08	0·93	1·26	0·90	0·80	1·02
LMIC other	1·25	0·98	1·61	0·76	0·60	0·96
LMIC MENA	2·05	1·58	2·67	0·84	0·63	1·12
Educational level						
Primary	1·17	0·99	1·37	1·19	1·06	1·34
Secondary	1·18	1·02	1·36	1·09	0·98	1·22
Post-secondary	1·00	1·00	1·00	1·00	1·00	1·00
Missing	1·12	0·84	1·51	1·03	0·79	1·35
Individual disposable income						
Lowest tertile	1·37	1·12	1·66	1·45	1·26	1·68
Mid tertile	1·17	0·97	1·42	1·22	1·06	1·40
Highest tertile	1·00	1·00	1·00	1·00	1·00	1·00
Sex						
Man	2·10	1·86	2·36	1·78	1·63	1·95
Woman	1·00	1·00	1·00	1·00	1·00	1·00
Days at risk	17,464,636			17,464,636		
N deaths	1,299			2,302		
N	274,542			274,542		

Table S3. Hazard ratios of COVID-19 mortality and mortality from other causes among individuals aged 70 and above in Stockholm county, by age group 70-79 and 80+, respectively. Cox regressions. All models control for individual age, sex, education, income, and country of birth.

	Aged 70-79						Aged 80+					
	COVID-19			All other causes of death			COVID-19			All other causes of death		
SqM per individual in household	b	min95	max95	b	min95	max95	b	min95	max95	b	min95	max95
0-	2.50	1.45	4.33	1.67	1.08	2.57	1.84	1.27	2.66	2.06	1.51	2.80
20-	2.46	1.65	3.68	1.41	1.04	1.91	1.54	1.17	2.02	1.95	1.57	2.41
30-	2.13	1.52	2.99	1.50	1.19	1.90	1.40	1.11	1.76	1.59	1.33	1.91
40-	1.32	0.98	1.78	1.02	0.84	1.25	1.07	0.87	1.30	1.12	0.96	1.30
60-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Missing	0.00	0.00	.	1.34	0.42	4.26	2.09	0.50	8.69	0.41	0.06	2.93
Age structure of household												
1 person household, 70+	2.06	1.57	2.71	1.49	1.24	1.80	1.44	1.19	1.75	1.31	1.13	1.52
Co-residing with someone older than 66	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Co-residing with someone aged 66 or younger	1.39	1.01	1.92	0.99	0.77	1.26	1.70	1.33	2.17	1.05	0.85	1.28
Housing												
Multi-family housing	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Single-family housing	1.07	0.77	1.49	0.81	0.64	1.01	1.05	0.84	1.32	1.15	0.98	1.36
Care home	6.72	4.96	9.09	5.16	4.05	6.56	3.82	3.13	4.67	2.20	1.87	2.59
N confirmed cases per 10,000 inhabitants in borough												
0-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10-	2.88	1.37	6.08	0.81	0.61	1.09	4.07	2.38	6.98	1.47	1.12	1.92
15-	2.12	1.01	4.45	0.71	0.53	0.94	3.43	2.02	5.84	1.47	1.14	1.90
20-	4.25	2.04	8.84	0.85	0.64	1.14	4.17	2.44	7.10	1.70	1.31	2.21
Individuals per SqKm in neighborhood												

0-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150-	1.75	0.84	3.64	1.17	0.80	1.72	0.99	0.58	1.69	1.00	0.70	1.42
500-	1.91	0.99	3.68	0.94	0.67	1.33	1.09	0.68	1.73	0.95	0.70	1.29
2000-	1.38	0.70	2.72	0.99	0.70	1.41	1.12	0.70	1.79	1.08	0.79	1.46
5000-	2.18	1.10	4.31	1.02	0.70	1.47	1.41	0.88	2.26	1.03	0.75	1.41
Country of birth												
Sweden	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HIC	1.01	0.76	1.35	0.87	0.70	1.08	1.11	0.92	1.33	0.91	0.79	1.05
LMIC other	1.31	0.90	1.90	0.74	0.51	1.07	1.16	0.82	1.63	0.78	0.57	1.06
LMIC MENA	1.66	1.10	2.51	0.98	0.65	1.45	2.31	1.63	3.26	0.73	0.48	1.11
Educational level												
Primary	1.58	1.19	2.10	1.49	1.22	1.83	1.04	0.86	1.26	1.06	0.92	1.22
Secondary	1.35	1.04	1.76	1.27	1.06	1.52	1.10	0.92	1.31	1.00	0.87	1.14
Post-secondary	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Missing	1.56	0.92	2.64	1.46	0.89	2.37	0.96	0.67	1.37	0.87	0.63	1.21
Individual disposable income												
Lowest tertile	1.63	1.17	2.29	1.52	1.21	1.91	1.15	0.90	1.46	1.31	1.09	1.58
Mid tertile	1.15	0.82	1.62	1.28	1.02	1.59	1.08	0.86	1.36	1.11	0.93	1.33
Highest tertile	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sex												
Man	1.86	1.50	2.29	1.92	1.65	2.24	2.10	1.82	2.43	1.63	1.46	1.83
Woman	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Days at risk	12,552,337			12,552,337			4,912,299			4,912,299		
N deaths	395			757			904			1,545		
N	196,663			196,663			77,879			77,879		

Table S4. Hazard ratios of COVID-19 mortality and mortality from other causes among individuals aged 70 and above in Stockholm county, by sex. Cox regressions. All models control for age, education, income, and country of birth.

	Men						Women					
	COVID-19			All other causes of death			COVID-19			All other causes of death		
SqM per individual in household	b	min95	max95	b	min95	max95	b	min95	max95	b	min95	max95
0-	1·78	1·16	2·75	1·42	0·98	2·06	2·11	1·37	3·24	2·33	1·66	3·28
20-	1·65	1·20	2·27	1·29	1·00	1·68	1·76	1·27	2·44	2·18	1·71	2·77
30-	1·74	1·33	2·26	1·44	1·18	1·77	1·38	1·04	1·83	1·61	1·31	1·97
40-	1·15	0·91	1·46	1·04	0·87	1·24	1·11	0·88	1·40	1·10	0·93	1·30
60-	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Missing	1·02	0·14	7·41	0·74	0·18	3·00	2·12	0·29	15·78	0·98	0·24	4·01
Age structure of household												
1 person household, 70+	1·86	1·51	2·29	1·46	1·25	1·71	1·47	1·15	1·88	1·37	1·15	1·63
Co-residing with someone older than 66	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Co-residing with someone aged 66 or younger	1·42	1·09	1·83	1·01	0·81	1·25	1·94	1·43	2·62	1·09	0·86	1·37
Housing												
Multi-family housing	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Single-family housing	1·09	0·85	1·41	0·87	0·72	1·04	0·96	0·72	1·29	1·14	0·94	1·38
Care home	4·17	3·28	5·30	2·75	2·24	3·37	4·17	3·27	5·32	2·46	2·04	2·96
N confirmed cases per 10,000 inhabitants in borough												
0-	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
10-	3·80	2·12	6·82	1·26	0·95	1·68	3·65	1·89	7·05	1·07	0·81	1·40
15-	3·16	1·77	5·62	1·24	0·94	1·63	2·94	1·54	5·62	1·01	0·78	1·31
20-	4·06	2·28	7·24	1·40	1·06	1·85	4·57	2·39	8·74	1·21	0·93	1·57
Individuals per SqKm in neighborhood												
0-	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00

150-	1·06	0·62	1·84	1·23	0·86	1·74	1·50	0·72	3·13	0·84	0·58	1·23
500-	1·23	0·78	1·96	0·99	0·72	1·34	1·54	0·78	3·04	0·83	0·60	1·16
2000-	1·11	0·69	1·79	1·12	0·82	1·53	1·53	0·77	3·02	0·92	0·66	1·28
5000-	1·53	0·94	2·46	1·00	0·72	1·39	1·95	0·98	3·87	0·96	0·68	1·35
Country of birth												
Sweden	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
HIC	1·09	0·87	1·36	1·02	0·86	1·22	1·07	0·86	1·32	0·83	0·70	0·97
LMIC other	1·40	1·01	1·95	0·76	0·55	1·07	1·09	0·73	1·62	0·79	0·56	1·11
LMIC MENA	2·28	1·63	3·20	0·92	0·63	1·33	1·81	1·17	2·79	0·80	0·50	1·26
Educational level												
Primary	1·09	0·88	1·35	1·19	1·00	1·41	1·30	1·02	1·65	1·19	1·01	1·41
Secondary	1·02	0·84	1·24	1·08	0·93	1·26	1·41	1·13	1·76	1·11	0·95	1·30
Post-secondary	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Missing	1·10	0·73	1·66	1·08	0·72	1·61	1·22	0·78	1·91	0·97	0·67	1·42
Individual disposable income												
Lowest tertile	1·46	1·13	1·90	1·39	1·14	1·68	1·15	0·85	1·56	1·58	1·25	2·00
Mid tertile	1·29	1·02	1·64	1·19	1·00	1·41	0·97	0·71	1·33	1·32	1·03	1·68
Highest tertile	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Days at risk	7,707,249			7,707,249			9,757,387			9,757,387		
N deaths	660			1,087			639			1,215		
N	121,232			121,232			153,310			153,310		

Stockholm Research Reports in Demography
Stockholm University,
106 91 Stockholm,
Sweden
www.su.se | info@su.se | ISSN 2002-617X

Stockholm University

Demography Unit