Residential context and COVID-19 mortality among adults aged 70 years and older in Stockholm: a population-based, observational study using individual-level data

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Summary

Background Housing characteristics and neighbourhood context are considered risk factors for COVID-19 mortality among older adults. The aim of this study was to investigate how individual-level housing and neighbourhood characteristics are associated with COVID-19 mortality in older adults.

Methods For this population-based, observational study, we used data from the cause-of-death register held by the Swedish National Board of Health and Welfare to identify recorded COVID-19 mortality and mortality from other causes among individuals (aged ≥70 years) in Stockholm county, Sweden, between March 12 and May 8, 2020. This information was linked to population-register data from December, 2019, including socioeconomic, demographic, and residential characteristics. We ran Cox proportional hazards regressions for the risk of dying from COVID-19 and from all other causes. The independent variables were area (m²) per individual in the household, the age structure of the household, type of housing, confirmed cases of COVID-19 in the borough, and neighbourhood population density. All models were adjusted for individual age, sex, country of birth, income, and education.

Findings Of 279 961 individuals identified to be aged 70 years or older on March 12, 2020, and residing in Stockholm in December, 2019, 274 712 met the eligibility criteria and were included in the study population. Between March 12 and May 8, 2020, 3386 deaths occurred, of which 1301 were reported as COVID-19 deaths. In fully adjusted models, household and neighbourhood characteristics were independently associated with COVID-19 mortality among older adults. Compared with living in a household with individuals aged 66 years or older, living with someone of working age (<66 years) was associated with increased COVID-19 mortality (hazard ratio 1·6; 95% CI 1·3–2·0). Living in a care home was associated with an increased risk of COVID-19 mortality (4·1; 3·5–4·9) compared with living in independent housing. Living in neighbourhoods with the highest population density (≥5000 individuals per km²) was associated with higher COVID-19 mortality (1·7; 1·1–2·4) compared with living in the least densely populated neighbourhoods (0 to <150 individuals per km²).

Interpretation Close exposure to working-age household members and neighbours is associated with increased COVID-19 mortality among older adults. Similarly, living in a care home is associated with increased mortality, potentially through exposure to visitors and care workers, but also due to poor underlying health among care-home residents. These factors should be considered when developing strategies to protect this group.

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Introduction

Older individuals are overrepresented among COVID-19 deaths,[1–6] raising questions of how to best mitigate patterns of social contact as the pandemic progresses.[7–10] Researchers have underlined the importance of living arrangements and household composition, such as care homes, crowded housing, and mixed-age households, as well as social contacts outside the household for understanding the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).[1–4,7,8,11–17] Living arrangements shape the contact that older adults have with individuals from within or outside the household. In addition, their risk of infection can be shaped by their broader neighbourhood environment. Residential clustering of infections has received considerable attention in previous studies.[12,14,15] 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.[11]

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 older people live is partly determined by their

Research in context

Evidence before this study

By mid-October, 2020, COVID-19 had caused more than 1 million deaths worldwide, and older people appear to have a greater risk of dying from COVID-19. Informed by studies on previous infectious disease epidemics, residential context was hypothesised to play a role in severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission due to the strength of social contacts among individuals residing in the same dwelling or in a densely populated neighbourhood. We searched PubMed, Google Scholar, medRxiv, and SocArXiv for studies published up to Aug 24, 2020, using the key words "household" or "neighbourhood" or "care home" or "elderly" or "older" combined with "coronavirus" or "SARS-CoV-2" or "COVID-19" and "mortality". We found one meta-analysis and systematic review of studies up to June 29, 2020, which showed that households are primary environments in which the virus is spread. In addition, research consistently shows that older adults are most at risk of developing severe COVID-19, and that individuals residing in care homes are particularly susceptible. Evidence on the role of neighbourhoods in exposing populations to the virus have been mixed. Neighbourhood density was largely found to be positively associated with numbers of COVID-19 cases, but the results are ambiguous and limited to aggregate-level associations. To date, no studies have examined how household and neighbourhood context are associated with COVID-19 mortality using individual-level data.

Added value of this study

We used Swedish administrative data and high-quality cause-of-death registration data to evaluate associations between COVID-19 mortality and neighbourhood and household characteristics of individuals aged 70 years and older in Stockholm county. To our knowledge, this is the first study to evaluate such associations using individual-level data based on a full population. We found that household structure was an important factor in COVID-19 mortality risk. Older adults in households with only other older adults were at lower risk of COVID-19 mortality than those in single-person and multigenerational households. Individuals in care homes were particularly at risk. We also found that neighbourhood characteristics (COVID-19 incidence in the borough and population density) were associated with COVID-19 mortality.

Implications of all the available evidence

Households and neighbourhoods are both important units in social mixing across age groups, which is associated with a greater risk of dying for older adults. Measures designed to protect older adults must consider community spread as well as individual vectors of transmission, such as family members and care-home employees.

sociodemographic characteristics and health, drawing individual-level conclusions on the basis of aggregated data can lead to biased conclusions on the importance of living arrangements and neighbourhoods in COVID-19 mortality.

In the present study, we use individual-level administrative data to analyse how mortality from COVID-19 in older adults is related to living arrangements and neighbourhood characteristics in Stockholm county, Sweden, a context in which a lockdown was never formally implemented, but which instead relied on the population adhering to recommendations of social distancing.[3] To our knowledge, this study is the first to use individual-level data to examine this relationship.[3] We compare our estimates to those of non-COVID-19 mortality, to identify which risk factors are specific to mortality from COVID-19.

Methods

Data sources and study population

For this population-based, observational study, we used data from the cause-of-death register held by the Swedish National Board of Health and Welfare, which distinguishes between recorded COVID-19 mortality and mortality from other causes.[18,19] This information is linked through unique personal identity numbers to administrative population-register data, including socioeconomic, demographic, and residential characteristics of all individuals living in Stockholm county, Sweden, in December, 2019, and who had been resident in Sweden for at least 2 years. We excluded all individuals who were younger than 70 years at the beginning of our observation period, which was from March 12, 2020 (the date of the first death from COVID-19 was March 13) until May 8, 2020, and anyone who had any missing data. The analyses were approved by the Swedish Ethical Review Authority, Dnr 2020-02199.

Procedures and outcomes

We accessed information on housing type, size of dwelling, and unique dwelling identifier from the Swedish dwelling register, which enabled us to link individuals who lived together in a household, and to assess the number of household members and their characteristics. By combining these sets of information, we created measures capturing area (m²) per individual in the household as a proxy of crowded living and household age structure. The household age structures were categorised as living alone; living exclusively with at least one individual aged 66 years or older; living with at least one individual younger than 66 years; living with at least one individual younger than 66 years and at least one child younger than 16 years; and all other living arrangements. Because a low number of COVID-19 deaths occurred among people living with at least one individual younger than 66 years and at least one child younger than 16 years, this category was combined with living with at least one individual younger than 66 years in the age-stratified and sex-stratified analyses. Furthermore, type of housing distinguished between single-family housing, multi-family housing, and care homes.

Neighbourhood characteristics were measured at two levels of aggregation. Incidence by borough measured confirmed COVID-19 cases per 10 000 inhabitants by April 14, 2020. From late January, testing for COVID-19 was mainly available only for symptomatic individuals who had travelled to risk areas, whereas from mid-March, most testing was of symptomatic individuals requiring hospital care (the majority of cases were reported after mid-March). Testing was equally available across Stockholm county during the study period.[20] The 39 boroughs in our data consisted of 14 city districts (stadsdel) in the city of Stockholm and the remaining 25 municipalities of Stockholm county (average population size 60 800). The caseload data were from Smittskydd Stockholm (appendix p 6) and the population size data refer to the end of 2019. The second measure, neighbourhood population density (number of individuals per km²), was computed for the 1313 demographic statistical areas constructed by Statistics Sweden, with an average population of 1800 (appendix pp 3–4).

Statistical analysis

All analyses were done in Stata 16.0. We did Cox proportional hazard regressions for death from COVID-19 and from all other causes. Individuals were recorded as either dying between March 12 and May 8, 2020, or being alive on May 8, 2020. Exposure time was calculated as the number of days from March 12, 2020, until death or May 8, 2020, whichever came first. We ran two separate regressions estimating the cause-specific hazard of dying from COVID-19, right-censoring at death from other causes; and the cause-specific hazard of dying from causes other than COVID-19, right-censoring at death from COVID-19.[21,22] In addition, we did analyses stratified by age (70–79 years vs ≥80 years) and sex. The results are presented as hazard ratios (HRs) with 95% CIs. In sensitivity checks, to avoid indirect effects from COVID-19 on all-cause mortality, we repeated our analyses for the same period in 2019, using all-cause mortality as the outcome. Our main independent variables were m² per individual in the household, the age structure of the household, type of housing, confirmed cases of COVID-19 in the borough, and neighbourhood population density. All models were adjusted for individual age, sex, country of birth, income, and education. All covariates were 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 were attained from the Swedish Total Population Register. Country of birth was categorised as Sweden; a high-income country other than Sweden; a low-income or middle-income country in the Middle East or north Africa; or another low-income and middle-income country. Income was derived from Swedish taxation registers and categorised into tertiles (low, middle, and high). Education data from Swedish educational registers was categorised into primary,

	n (%)	Deaths from COVID-19	Exposure time, person-years*	COVID-19 deaths per 1000 person-years
m² per individual in household				
0 to <20	7859 (2·9%)	88	1211	73
20 to <30	19 323 (7·0%)	183	2984	61
30 to <40	43 278 (15·8%)	325	6692	49
40 to <60	89 081 (32·4%)	320	13 839	23
≥60	114 228 (41·6%)	383	17 743	22
Missing	943 (0·3%)	<5	147	14
Age structure of household				
Living alone	110 744 (40·3%)	737	17 140	43
Living with at least one person ≥66 years old	125 023 (45·5%)	363	19 432	19
Living with at least one person <66 years old	33 035 (12·0%)	168	5128	33
Living with at least one person <66 years old and at least one child <16 years old	5500 (2·0%)	32	853	38
Other	410 (0·1%)	<5	64	16
Housing				
Multi-family housing	173 179 (63·0%)	702	26 885	26
Single-family housing	90 655 (33·0%)	219	14 100	16
Care home	10 878 (4·0%)	380	1632	233
Incidence of COVID-19 per 10 000 inhabitants in borough				
0 to <10	20 581 (7·5%)	23	3200	7
10 to <15	48 230 (17·6%)	218	7484	29
15 to <20	122 000 (44·4%)	546	18 930	29
≥20	83 900 (30·5%)	514	13 002	40
Individuals per km² in neighbourhood				
0 to <150	19 233 (7·0%)	34	2991	11
150 to <500	17 732 (6·5%)	62	2753	23
500 to <2000	60 125 (21·9%)	243	9338	26
2000 to <5000	68 418 (24·9%)	304	10 611	29
≥5000	109 204 (39·8%)	658	16 924	39
Country of birth				
Sweden	217 785 (79·3%)	928	33 791	27
High-income country	37 517 (13·7%)	211	5818	36
LMIC in Middle East and north Africa	7550 (2·7%)	83	1168	71
Other LMIC	11 860 (4·3%)	79	1839	43
Educational level				
Primary	61 988 (22·6%)	415	9588	43
Secondary	106 894 (38·9%)	506	16 586	31
Post-secondary	99 875 (36·4%)	308	15 524	20
Missing	5955 (2·2%)	72	919	78

(Table continues on next page)

See Online for appendix

	n (%)	Deaths from COVID-19	Exposure time, person-years*	COVID-19 deaths per 1000 person-years
(Continued from previous page)				
Individual disposable income tertile				
Low	115 518 (42·1%)	709	17 892	40
Middle	98 421 (35·8%)	439	15 272	29
High	60 773 (22·1%)	153	9452	16
Sex				
Female	153 395 (55·8%)	640	23 810	27
Male	121 317 (44·2%)	661	18 806	35
Total	274 712 (100·0%)	1301	42 616	31

LMIC=low-income or middle-income country. *Exposure time was calculated as the number of days from March 12, 2020, until death or May 8, 2020, whichever came first, divided by 365·25.

***Table:* Characteristics and mortality from COVID-19 among individuals aged 70 years and older in Stockholm**

secondary, or post-secondary education, or missing information.

Role of the funding source

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

Results

279 961 individuals were identified to be aged 70 years or older on March 12, 2020, and residing in Stockholm in December, 2019. Of these, 217 individuals were excluded for not having lived in Sweden for 2 years, and a further 5032 individuals were excluded because of missing data (appendix p 1). 274 712 individuals were included in the study population (table). 3386 individuals died during the study period and 1301 of these deaths were reported as COVID-19 deaths by the Swedish National Board of Health and Welfare. COVID-19 was identified as the underlying cause of death in 1252 of 1301 cases (emergency International Classification of Diseases [ICD] version 10 codes U07.1, U07.2, or B34·2) and in the remaining 49 cases, ICD emergency codes U07.1, U07.2, or B34.2 were listed as contributing causes of death.

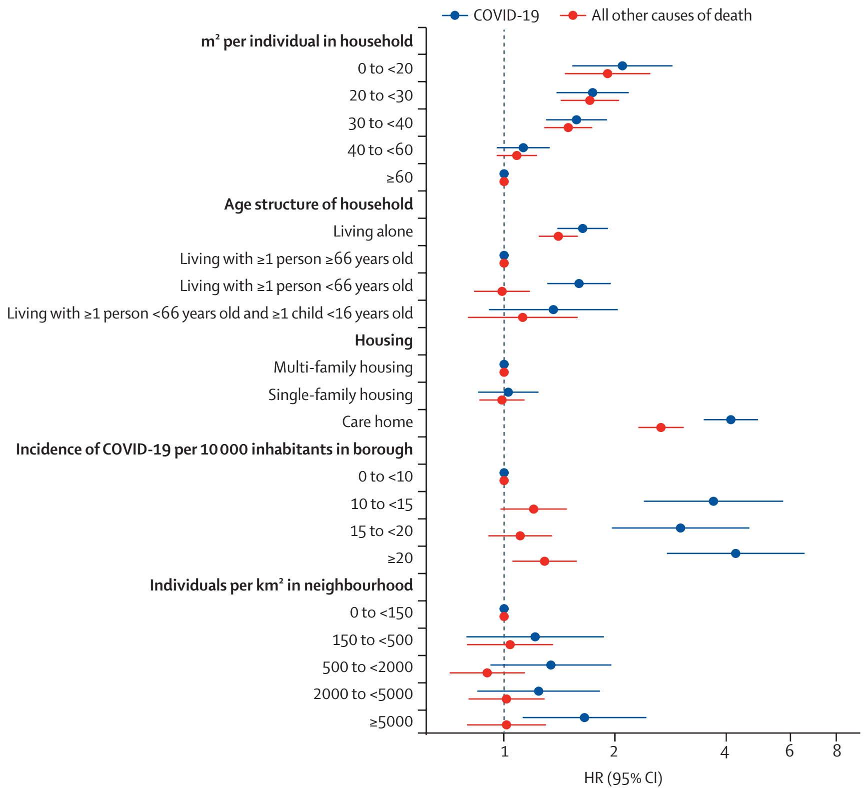
Older adults living in the most crowded households (0 m² to <20 m² per individual) had higher COVID-19 mortality (73 deaths per 1000 person-years) than those living in the least crowded households (≥60 m² per individual; 22 deaths per 1000 person-years; table). In the fully adjusted Cox regression models of COVID-19 mortality and mortality from all other causes, living in the most crowded households was associated with an increased hazard of death from both COVID-19 (HR 2·1; 95% CI 1·5–2·9) and other causes (1·9; 1·5–2·5) compared with living in the least crowded households (figure 1; appendix p 7).

In terms of the age structure of the household, the lowest COVID-19 mortality was among individuals living with someone aged 66 years or older (19 deaths per 1000 person-years), with higher mortality among those living with someone of working age (<66 years; 33 deaths per 1000 person-years) and those living alone (43 deaths per 1000 person-years; table). In the fully adjusted models (figure 1), compared with individuals living with someone aged 66 years or older, COVID-19 mortality was higher among individuals living alone (HR 1·6; 95% CI 1·4–1·9) and individuals living with someone younger than 66 years (1·6; 1·3–2·0). For individuals living with someone younger than 66 years, the hazard of COVID-19 mortality was notably higher than the corresponding hazard for mortality from other causes of death (1·0; 0·8–1·2), whereas for living alone, the CIs for COVID-19 mortality overlap with those for mortality from other causes (1·4; 1·2–1·6). Individuals who were living with both an individual younger than 66 years and a child younger than 16 years (1·4; 0·9–2·0) had similar COVID-19 mortality to those living with an individual younger than 66 years and no children (1·6; 1·3–2·0).

In the unadjusted models (table), individuals living in multi-family housing (26 deaths per 1000 person-years) had higher mortality than those living in single-family housing (16 deaths per 1000 person-years). However, no difference was seen when adjusting for population density (figure 1). Individuals in care homes had the highest mortality (233 deaths per 1000 person-years), and in the fully adjusted models, care-home residents had considerably higher COVID-19 mortality compared with individuals living in multi-family housing (HR 4·1; 95% CI 3·5–4·9). Care-home residents also had increased mortality from other causes of death, but the corresponding HR (2·7; 2·3–3·1) was lower than that for COVID-19 mortality.

Mortality among individuals living in boroughs with the highest numbers of confirmed COVID-19 cases (≥20 cases per 10 000 inhabitants; 40 deaths per 1000 person-years) was higher than among those living in the least affected boroughs (0 to <10 cases per 10 000 inhabitants; 7 deaths per 1000 person-years). An increased hazard of mortality in the boroughs with the highest numbers of COVID-19 cases was also seen in the fully adjusted models (HR 4·3; 95% CI 2·8–6·6). In the most affected boroughs, mortality from other causes was also significantly higher compared with the least affected boroughs (1·3; 1·1–1·6).

COVID-19 mortality was higher in the most densely populated neighbourhoods (≥5000 individuals per km²; 39 deaths per 1000 person-years) than in the most sparsely populated neighbourhoods (0 to <150 individuals per km²; 11 deaths per 1000 person-years; table). In the fully adjusted models, the difference between the most and least densely populated neighbourhoods was significant (HR 1·7; 95% CI 1·1–2·4), but the differences between other groups were not significant. We found no associations between population density and other



	HR (95% CI) COVID-19	HR (95% CI) All other causes of death
m² per individual in household		
0 to <20	2·10 (1·53–2·87)	1·91 (1·46–2·50)
20 to <30	1·74 (1·39–2·18)	1·71 (1·42–2·05)
30 to <40	1·57 (1·30–1·90)	1·49 (1·29–1·74)
40 to <60	1·13 (0·95–1·33)	1·08 (0·95–1·23)
≥60	1·00 (1·00–1·00)	1·00 (1·00–1·00)
Age structure of household		
Living alone	1·64 (1·40–1·92)	1·40 (1·24–1·59)
Living with ≥1 person ≥66 years old	1·00 (1·00–1·00)	1·00 (1·00–1·00)
Living with ≥1 person <66 years old	1·60 (1·31–1·95)	0·99 (0·83–1·18)
Living with ≥1 person <66 years old and ≥1 child <16 years old	1·36 (0·91–2·04)	1·12 (0·80–1·58)
Housing		
Multi-family housing	1·00 (1·00–1·00)	1·00 (1·00–1·00)
Single-family housing	1·03 (0·85–1·24)	0·99 (0·86–1·14)
Care home	4·13 (3·49–4·90)	2·67 (2·32–3·07)
Incidence of COVID-19 per 10 000 inhabitants in borough		
0 to <10	1·00 (1·00–1·00)	1·00 (1·00–1·00)
10 to <15	3·71 (2·40–5·73)	1·20 (0·98–1·48)
15 to <20	3·02 (1·96–4·64)	1·11 (0·91–1·35)
≥20	4·26 (2·77–6·55)	1·29 (1·05–1·58)
Individuals per km² in neighbourhood		
0 to <150	1·00 (1·00–1·00)	1·00 (1·00–1·00)
150 to <500	1·21 (0·79–1·87)	1·04 (0·79–1·36)
500 to <2000	1·34 (0·92–1·96)	0·90 (0·71–1·14)
2000 to <5000	1·24 (0·85–1·82)	1·02 (0·80–1·29)
≥5000	1·65 (1·12–2·44)	1·02 (0·79–1·30)

Figure 1: **Cox proportional hazard regression for death from COVID-19 and from all other causes among individuals aged 70 years and older**
All models control for individual age, sex, education, income, and country of birth. HR=hazard ratio.

causes of death. In the sensitivity analysis using all-cause mortality for the same dates in 2019 as the outcome (appendix p 5), we found similar patterns with the exception of population density in the neighbourhood, which was positively associated with mortality from other causes in 2019, but not in 2020.

With respect to sociodemographic characteristics, individuals with the lowest tertile of income (40 deaths per 1000 person-years), low education (primary only; 43 deaths per 1000 person-years), and those born in low-income or middle-income countries in the Middle East and north Africa (71 deaths per 1000 person-years) had higher COVID-19 mortality than individuals with high income (16 deaths per 1000 person-years), high education (post-secondary; 20 deaths per 1000 person-years), and those born in Sweden (27 deaths per 1000 person-years), respectively.

In Cox regressions on COVID-19 mortality stratified by age group (figure 2, appendix pp 8–9), the largest difference between individuals aged 70–79 years and individuals aged 80 years or older was in the association between living in a care home (*vs* multi-family housing) and COVID-19 mortality. Individuals aged 70–79 years had higher excess mortality if they lived in a care home (HR 6·7; 95% CI 4·9–9·0) compared with individuals aged 80 years and older (3·8; 3·1–4·7). Individuals aged 70–79 years who lived in a care home also had higher mortality from causes other than COVID-19 (5·5; 4·3–7·0). In terms of living with someone younger than 66 years, for individuals aged 70–79 years, the CIs of COVID-19 mortality (1·4; 1·0–1·9) overlapped with those of mortality from other causes (1·0; 0·8–1·3), whereas among individuals aged 80 years and older, living with someone younger than 66 years was associated with excess mortality from COVID-19 (1·7; 1·3–2·2), but not from other causes (1·0; 0·8–1·2). We found no differences by age group in the positive association between the number of cases per 10 000 inhabitants of the borough and COVID-19 mortality. Among individuals aged 80 years and older, we found an additional increase in mortality from causes other than COVID-19 among individuals who lived in an area with 10 COVID-19 cases per 10 000 inhabitants or more compared with the least affected areas (10 to <15 cases per 10 000 inhabitants: 1·6, 1·2–2·1; 15 to <20 cases: 1·5, 1·1–2·0; ≥20 cases: 1·7, 1·3–2·3).

In Cox regressions of mortality stratified by sex (figure 3, appendix pp 10–11), the main difference was that women who lived in care homes (*vs* multi-family

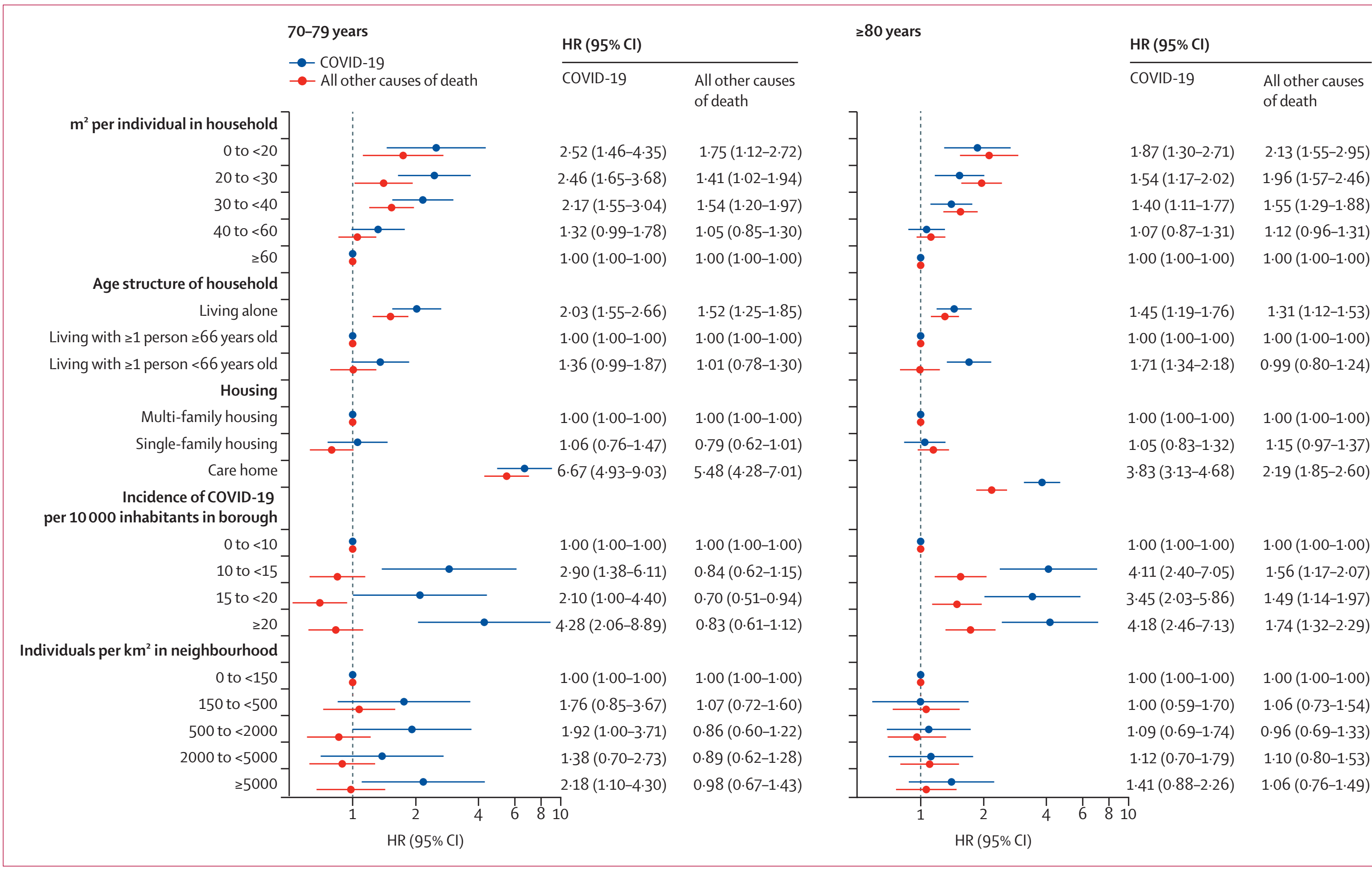


***Figure 2:* Cox proportional hazard regression for death from COVID-19 and from all other causes, stratified by age group**
All models control for individual age, sex, education, income, and country of birth. HR=hazard ratio.

housing) had higher excess mortality from COVID-19 (HR 4·1; 95% CI 3·2–5·3) compared with mortality from other causes (2·5; 2·0–3·0), whereas for men, the CI overlapped with that of mortality from other causes (COVID-19: 4·3, 3·4–5·5; other causes: 2·9, 2·3–3·6). Overall, there were few interactions between sex and our independent covariates in COVID-19 mortality.

Discussion

In this population-based, observational study, we analysed how residential characteristics were associated with COVID-19 mortality between March 12 and May 8, 2020, the period covering the peak excess mortality in Stockholm, which was the epicentre of the pandemic in Sweden (appendix p 2). We found that living arrangements and neighbourhood characteristics are independently associated with mortality from COVID-19 among people aged 70 years and older in Stockholm county, after adjusting for age, sex, education, income, and country of birth. Epidemiological research on SARS-CoV-2 has indicated that households are important sites for virus transmission.[12,14–16,23] Consequently, housing type and household composition have been suggested as correlates of infection as well as of differences in mortality between regions and countries.[7,24] The results from our fully adjusted models, which compared mortality from COVID-19 and other causes of death, identified two specific living arrangements as risk factors for COVID-19 mortality.

First, living in mixed-age households (as compared with living with other older adults) was associated with higher COVID-19 mortality, consistent with the previous suggestion of a higher risk of SARS-CoV-2 infection in these households through indirect exposure to outside social groups.[1] This association does not exist for other causes of death, suggesting that individuals with poorer baseline health are not more likely to reside in such households. Multigenerational living could therefore have contributed to COVID-19 mortality in countries where it is common.[25] Of note, older adults who exclusively live with other older adults had a low risk of COVID-19 mortality, suggesting that this group was able to successfully self-isolate, at least in Stockholm. Online purchases of essentials became common during the COVID-19 pandemic, and online doctors were available already before the pandemic, which could have enabled the successful self-isolation in this group.

Second, our findings confirm the high COVID-19 mortality in care homes. The excess COVID-19 mortality

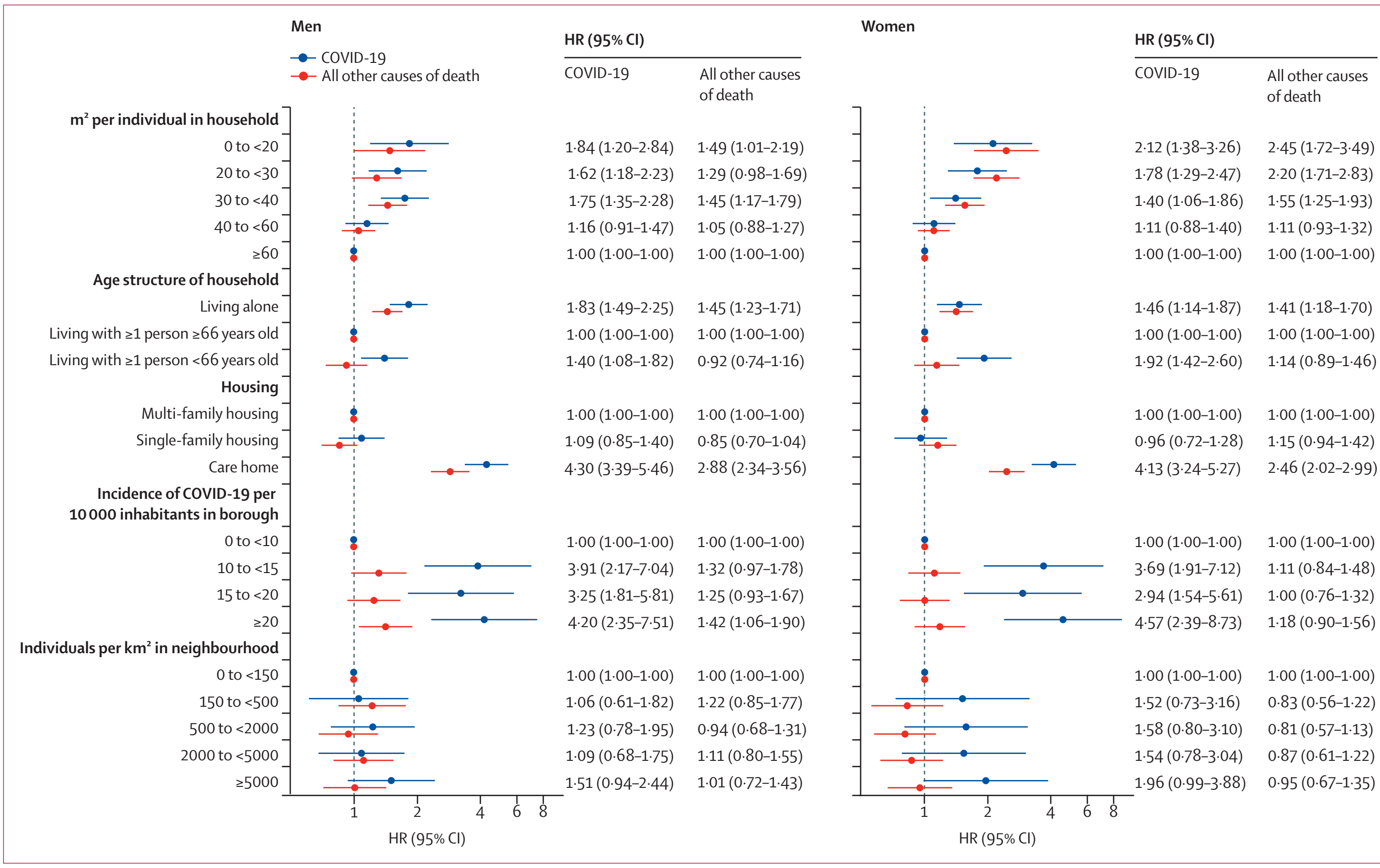


***Figure 3:* Cox proportional hazard regression for death from COVID-19 and from all other causes, stratified by sex**
All models control for individual age, education, income, and country of birth. HR=hazard ratio.

among individuals living in care homes was attenuated in the fully adjusted model, but remained high, and was higher than the excess mortality from other causes of death during the same period. The Swedish Government implemented restrictions to care home visitation on April 1, 2020,[26] although most care homes in Stockholm introduced it earlier.[27] Sweden experienced an initial shortage of personal protective equipment,[28,29] which could have increased COVID-19 mortality in care homes. 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, indicates that COVID-19 deaths in care homes were in large part also due to the high proportion of individuals who were older and frail. A study from 2006 to 2012 in Sweden found that in 2012, 50% of all care-home residents in the Kungsholmen borough of Stockholm died within 595 days, indicating that individuals who are particularly frail tend to live in such homes.[30]

In terms of other living arrangements, living alone or in more crowded housing was associated with similarly high mortality from COVID-19 and other causes of death[7,21] suggesting no additional risk from COVID-19, but rather unobserved frailty among older individuals in these living arrangements.[31] We did not find any difference in COVID-19 mortality between older people living in multi-family and single-family housing. Therefore, 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. One plausible explanation is that older individuals are able to avoid exposure to these common spaces, such as by receiving help with shopping or avoiding interaction in these spaces.

The importance of neighbourhood transmission of SARS-CoV-2 has been contested;[11,32] however, previous studies have not examined the role of neighbourhood exposure at the individual level. We used two neighbourhood-level measures to assess how COVID-19 mortality among older adults was associated with 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 in the borough). We found a stronger association with the number of confirmed cases in the borough. Compared with boroughs with no or few confirmed cases (0 to <10 per 10 000 residents), older adults living in boroughs with higher numbers of cases had increased mortality from COVID-19 but not from other causes. This was a threshold effect, with no gradient in COVID-19 mortality with successively increasing borough-level caseloads. Additionally, we found indications of increased COVID-19 mortality in more densely populated neighbourhoods, but the estimates were imprecise. These findings indicate that neighbourhood transmission is an important consideration for COVID-19, even if the population aged 70 years and older had to a large extent been self-isolating.

Population register data have many advantages, but they capture de jure rather than de facto characteristics of individuals. The dataset probably underestimates the number of individuals living in care homes, because the individuals who are most frail sometimes die before their move into a care home has been registered, or because we misclassify individuals who moved into care homes in 2020, by measuring their housing situation in 2019. We also did not have any information about whether an individual living independently was receiving at-home care. Furthermore, mortality from other causes, which we used as a comparison, was occurring in a setting in which COVID-19 exists, and thus could capture indirect COVID-19 effects (collateral deaths). For example, the fear of contracting SARS-CoV-2 could affect the care-seeking behaviours of individuals, which could in turn increase the risk of other causes of death.[33] Based on our sensitivity analysis, the association between our studied variables and all-cause mortality in 2019 was overall similar to what we observed for mortality from other causes in 2020, suggesting that COVID-19 did not have a substantial indirect impact on mortality from other causes. An additional limitation of this study is that although the Swedish data on COVID-19 deaths are considered accurate, we cannot rule out some misclassification of COVID-19 deaths. Finally, the measure of the number of positive COVID-19 cases in the borough has three limitations. First, it captured only individuals with symptoms severe enough to be tested in hospital care, meaning that it underestimates the number of actual cases. Second, boroughs are large, and individuals in the same borough are not necessarily interacting. Accessing data on reported cases at a finer granularity, both in terms of symptoms and spatial resolution, would be useful to more accurately assess how neighbourhood transmission is associated with COVID-19 mortality. Third, we cannot rule out confounding by other unobserved neighbourhood characteristics. We also stress that our findings might not be generalisable to other countries, where the COVID-19 pandemic was handled differently.

To the best of our knowledge, this is the first study to empirically evaluate the importance of residential context for COVID-19 mortality among older adults, while adjusting for potential confounders using individual-level data and comparing with mortality from other causes. In Sweden, a setting with a distinct approach to handling the pandemic and widespread transmission of SARS-CoV-2, the close exposure to working-age individuals, in the form of care workers, household members, or neighbours, could have detrimental effects on the survival of older adults during the COVID-19 pandemic. Strategies to protect individuals in care homes, in densely populated areas, and in families with multi-generational living arrangements might increase survival among the older population.

Contributors

MB jointly conceived the study with SA, MK, SD, BM, and EM. MB, BM, MR, GA, and AC provided the data. MB analysed the data. BM created the maps. MB, SA, MK, JH, SD, and EM wrote the manuscript and GA edited the manuscript. EM coordinated the project. GA supervised the project. All authors read and approved the final version of the manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

This study was produced under the Swedish Statistics Act, according to which privacy concerns restrict the availability of register data for research. Aggregated data can be made available by the authors, subject to ethical vetting. Enquiries should be made to the corresponding author. The authors accessed individual-level data through Statistics Sweden's micro-online access system, MONA.

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