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## Pre-print Abstract

As global deaths from COVID-19 continue to rise, the world's governments, institutions, and agencies are still working toward an understanding of who is most at risk of death. Owing to the special provision of new data from the Swedish authorities, we have access to data on all recorded COVID-19 deaths in Sweden up to May 7, 2020 linked to high-quality and accurate individual-level background data from administrative registers. Using individual-level survival analysis we demonstrate that being male, having less disposable income, a lower education level, not being married, and being an immigrant from a low- or middle-income country all independently predict a higher risk of death from COVID-19. We also observe differences in these patterns between working age and retirement age individuals. The role of socio-economic characteristics is more pronounced at working ages, whereas the role of one's marital status is more pronounced at retirement ages. The main message is that while COVID-19 does not discriminate, the interaction of the virus and its social environment exerts unequal burden on the most disadvantaged members of society.

**Keywords:** COVID-19, mortality, death risk, socio-demographic, Sweden

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## Introduction

As global deaths from COVID-19 continue to rise (1), the world's governments, institutions, and agencies are still working toward an understanding who is most at risk of death. This is due to a lack of high-quality micro-level data linking death records to other data sources (e.g. censuses, surveys and registers) that contain information on socio-demographic background characteristics associated with variation in the risk of death. Until now, our understanding has been limited to rudimentary inferences drawn from comparisons of counts or proportions for different sections of society, more formal analyses of highly aggregated data, and a small number of micro-level analyses focused on comorbidities that give scant attention to socio-demographic factors beyond age and sex. These initial findings suggest that men (2–6), the elderly (2–11), racial and ethnic minorities (4, 6, 7, 12), and people occupying lower socioeconomic positions (4, 6), are more prone to developing severe COVID-19, or dying from it. In light of the widely adopted message that COVID-19 'does not discriminate', one given credence by the Director-General of the World Health Organisation (13), these patterns have been met with alarm. Indeed, they have spurred calls for the release of more detailed case and fatality data that would permit a more rigorous investigation of the apparent socio-demographic variation in COVID-19 death (8). In response to this call, the present study examines sociodemographic risk factors of COVID-19 mortality in Sweden.

Owing to the special provision of new data from the Swedish authorities, we have access to data on all recorded COVID-19 deaths in Sweden up to May 7 2020 linked to high-quality and accurate individual-level background data from the administrative registers. Using these data, we aim to advance the understanding of the socio-demographic risk factors associated with the risk of COVID-19 death for the entire population of Sweden. To elaborate, we examine multivariate variation in the risk of death from characteristics that include age, sex, civil status, education level, disposable income, region of residence, and country of birth. Our findings, which reveal marked variation in the risk of death from COVID-19 across these fundamental socio-demographic characteristics, should be of interest to decision makers in all countries. As many nations now begin to ease distance restrictions and plan a roadmap through the pandemic, the provision of reliable information on which members of society are most at risk of death will be essential to informing national strategy. Compared to most other nations, Sweden has taken a less-restrictive approach to containing COVID-19 by promoting social distancing rather than mandating quarantine. As such, the results from the present study are not only important for the Swedish context, but can be informative for countries gradually easing restrictions to identify vulnerable populations.

### Materials and Methods

The data for this study are all 3,135 deaths reported to be associated with COVID-19 between Jan 1, with the first actual death observed on March 5, and May 7, 2020 in Sweden who have been resident in the country for at least two years. These deaths have been collected by the Swedish National Board of Health and Welfare, the agency responsible for the cause of death register, and match the death counts reported to the public. Out of all 3,135 deaths, COVID-19

was identified as the underlying cause of death in 2,971 cases (emergency ICD code U07.1 or U07.2). In the remaining 164 cases, ICD emergency codes U07.1 or U07.2 were listed in contributing causes of death not reported as the underlying cause of death. Given the timeliness of the data, the assignment of the underlying cause of death should be understood as preliminary. Thanks to the unique personal identification number, each individual COVID-19 death was then linked to a collection of Swedish administrative registers, which includes individual socio-demographic information for all individuals living in Sweden between 1968 and the end of 2019. We excluded ten deaths from the analysis because of missing information on key variables. In our final dataset we study 3,125 deaths among 7.68 million individuals aged 21 and above.

Cox proportional hazard regression models were estimated to obtain hazard ratios for the risk of dying from COVID-19 between Jan 1, 2020 and May 7, 2020. We restricted our study population to adults aged 21 up to the highest observed age in Swedish registers. The underlying time process of the Cox model is biological age measured with monthly precision. All of the covariates are time-constant and either measured at the end of 2019 (sex, marital status, country of birth, living in Stockholm) or 2018 (highest achieved educational degree, individual disposable income). We adjust for whether an individual lives in Stockholm since it is the epicenter of the virus in Sweden (The Public Health Agency of Sweden). All analyses were conducted in Stata 16.0.

## Results

Figure 1 compares the mortality risks from COVID-19, separately for men and women, controlled for age from a multivariate Cox survival analysis. For men and women alike, never-married, separated or divorced, and widowed individuals experience approximately 1.5 to 2 times higher mortality from COVID-19 relative to those who are married. We include socio-economic position as measured by, both, education and disposable income in 2018 for both sexes. With respect to education, and net of income, we find a gradient for both men and women with individuals with secondary education experiencing approximately 25% ($HR_{Men}$: 1.24; 95% CI: 1.08, 1.42) and 35% ($HR_{Women}$: 1.36; 95% CI: 1.16, 1.60) higher mortality, respectively, than individuals with post-secondary education, and those with primary education experiencing approximately 25% ($HR_{Men}$: 1.23; 95% CI: 1.07, 1.42) and 50% ($HR_{Women}$: 1.48; 95% CI: 1.25, 1.75) higher mortality, respectively, relative to the same reference group. We also find an income gradient, net of education, for men but not for women. Among men, the gradient is most pronounced with individuals in the first and second tertiles of disposable income experiencing approximately 80% ($HR_{Q1}$: 1.76; 95% CI: 1.49, 2.09) and 50% ($HR_{Q2}$: 1.53; 95% CI: 1.30, 1.80) higher mortality, respectively, relative to those in the top tertile. Among women we find no clear income gradient with those in the first tertile experiencing approximately 25% ($HR_{Q1}$: 1.25; 95% CI: 1.00, 1.57) higher mortality, while those in the second tertile experience nearly 10% lower mortality ($HR_{Q2}$: 0.92; 95% CI: 0.73, 1.17) compared to those in the top tertile. Immigrants from low and middle income countries displayed approximately 2.5 times higher mortality among men ($HR_{Men}$: 2.56; 95% CI: 2.18, 3.01) and more than 1.5 times higher among women ($HR_{Women}$: 1.66; 95% CI: 1.32, 2.09) as

compared to those born in Sweden, ceteris paribus; whereas immigrants from high income countries only displayed 20% higher mortality among men ($HR_{Men}$: 1.19; 95% CI: 1.01, 1.39) and nearly 10% higher among women ($HR_{Women}$: 1.08; 95% CI: 0.92, 1.26). Finally, the variable that has the strongest impact on COVID-19 mortality is living in Stockholm County, as compared to living in the rest of Sweden, which is associated with approximately 4.5 times higher mortality. To a large extent all these patterns are produced by the many COVID-19 deaths that are observed at the advanced ages.

Figure 1: Hazard ratios of dying from COVID-19 for men and women in Sweden

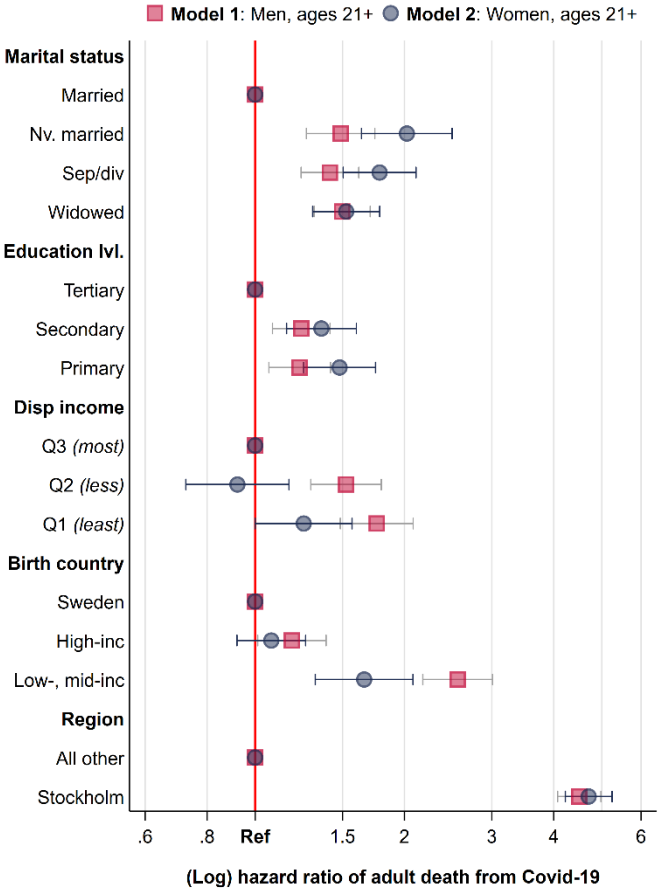
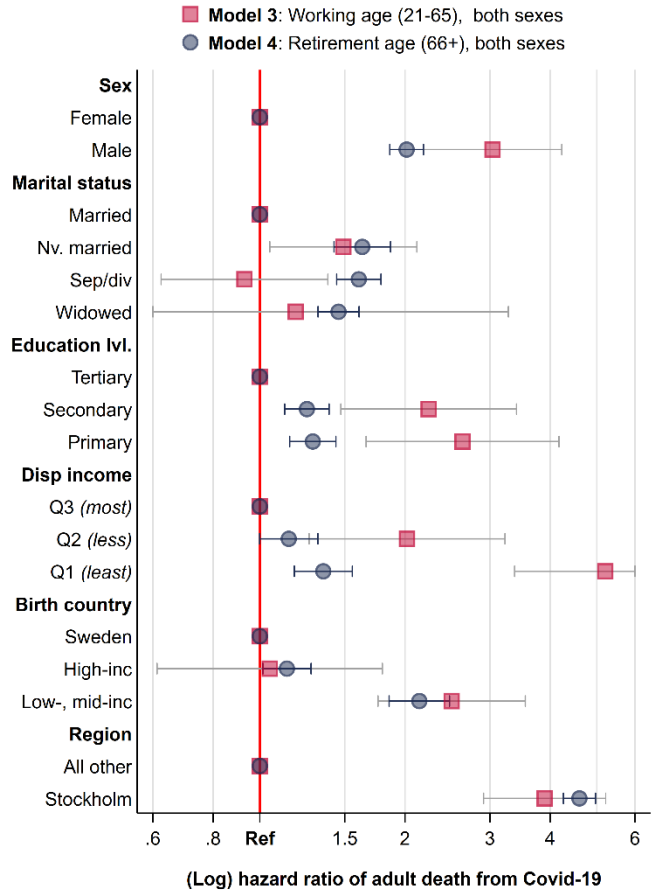



Figure 2 presents the results comparing mortality risks from COVID-19 stratified for individuals in working age (ages 65 and below) and retirement age (ages 66 and higher) in a multivariate setup that also includes continuous age within each age segment. Due to the lower number of deaths in the younger strata, the confidence intervals for the estimated death risks of this group are much larger than for the elderly. In this analysis, we still find substantial differences in the demographic risk factors between working age people and retirees. In working ages relative to retirees, males experience even higher mortality relative to females, and education and income are stronger predictors of dying from COVID-19. In working ages, those in the lowest income tertile are more than 5 times as likely to die (HR: 5.21; 95% CI:

3.38, 8.02) from COVID-19 than those in the highest, and those with primary (HR: 2.63; 95% CI: 1.66, 4.18) and secondary (HR: 2.02; 95% CI: 1.27, 3.22) education are twice as likely to die relative to those with post-secondary education. Among individuals in retirement ages, the socio-economic differentials in COVID-19 mortality are much less pronounced, this holds both for the independent roles of educational attainment and (pension) income. In contrast to those in working ages, we find more pronounced differences by civil status among the older population. Specifically, mortality relative to married individuals was approximately 45% higher among widows and widowers (HR: 1.46; 95% CI: 1.32, 1.61), 60% higher for individuals who were separated or divorced (HR: 1.60; 95% CI: 1.44, 1.78), and nearly 65% higher for those who were never married (HR: 1.63; 95% CI: 1.43, 1.87). In the working age population, significant excess mortality is only observed for those who were never married (HR: 1.49; 95% CI: 1.27, 1.74). Among immigrants, individuals from low and middle-income countries are more than twice as likely to die as compared to individuals born in Sweden in both age segments. The excess mortality associated with living in Stockholm is also very similar for the two age groups.

Figure 2: Hazard ratios of dying from COVID-19 for working ages (191 deaths) and retirement ages (2,934 deaths)



## Discussion

Here, we provide the first comprehensive study of socio-demographic risk factors of COVID-19 death using complete, detailed, and high-quality micro-level data for an entire national population. Specifically, in addition to being in older ages, we show that being male, having less (or no) disposable income, having a lower education level, not being married, and being born in a low- or middle-income country all independently predict a higher risk of death from COVID-19. We also find important differences in the patterns between the working age and retirement age populations, in the more pronounced role of socio-economic characteristics at working ages and the more pronounced role of marital status at retirement ages. Our findings have direct relevance to Sweden *and* important implications for other Western countries looking to ease lockdown restrictions in favor of the more open strategy adopted by Sweden from the outset. Our study provides valuable insight for countries preparing for the challenges associated with trying to *live with the virus*.

Despite the widely assumed notion that the virus *does not* discriminate, we definitively show that the interaction of the virus and its environment *does* discriminate, exerting an unequal burden on the most disadvantaged members of society. Beyond the strong effects of age on COVID-19 mortality, we find that disadvantaged sub-populations show elevated COVID-19 mortality risk – as is the case for most other causes of death and mortality in general (14, 15). However, the robust finding of elevated mortality among immigrants from low and middle-income countries deviates from findings on other causes of death such as neoplasms or circulatory diseases, where immigrants tend to have *lower* mortality than natives (16). This finding may help guide governmental policy, and may be of relevance for other high-income countries as well. Better health care resources may need to be allocated towards communities with many foreign-born individuals.

Previous research shows that people with less strong socio-economic resources are more vulnerable to poor health and mortality from different causes of death, as we find here. However, more research is needed to understand the mechanisms behind low-income and low-educated individuals' excess COVID-19 mortality. In addition to pre-existing health conditions, precarious employment, not having access to a car, and crowded housing are all factors that could be important to understand this relationship. Future research on COVID-19 mortality also needs to pay better attention to foreign-born people. Research is needed to understand to which extent their elevated COVID-19 mortality is related to factors such as pre-existing health conditions, trans-national activities, living arrangements, occupations, and the characteristics of the neighborhoods in which they live. Many of these factors are also important in relation to the excess mortality associated with low education and low incomes. Of particular interest would be to understand if migrants are more susceptible to severe outcomes of the disease once infected, or if excess mortality is related to transmission pathways. Here we demonstrate that we find a migrant disadvantage after adjusting for socioeconomic characteristics, and region of residence in Sweden.

For people in pension age, Swedish policy has been directed to reduce intergenerational contact. The number of multi-generational households in Sweden is otherwise relatively low (17). Our results show that unmarried elderly people are at particularly high risk of dying from COVID-19. This is the segment of the population that is in higher need than others to rely on external assistance in their home, or who lives in a care home. Future research needs to study in more detail how different characteristics of old people's housing arrangements, including elderly care and home-help services, have been related to COVID-19 mortality.

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## Author contribution statement

S.D. jointly conceived the study with E.M., S.A., and M.W.. G.A., B.M., and M.B. provided the data. S.D. analyzed the data. S.D., M.W., E.M., S.A., M.K. wrote the manuscript; G.A. and M.B edited the manuscript. G.A. supervised the project. All the 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-vetting authority, Dnr 2020-02199.

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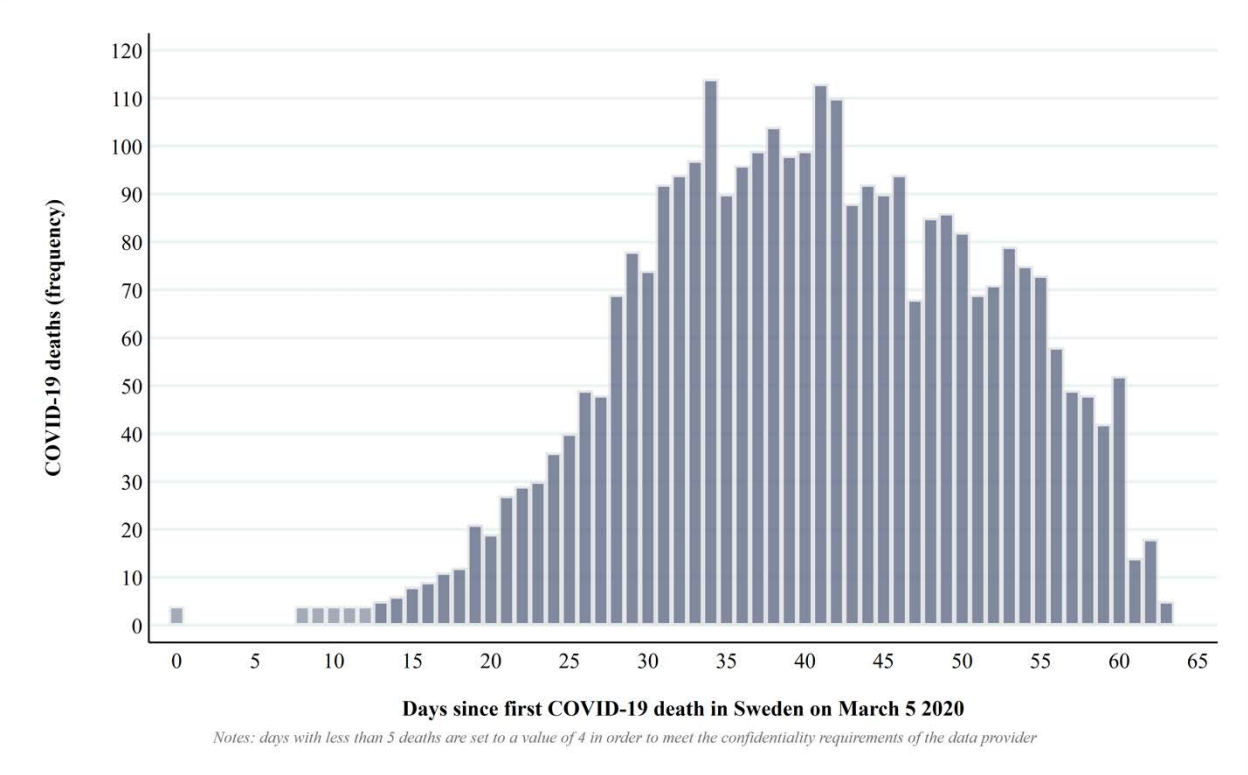
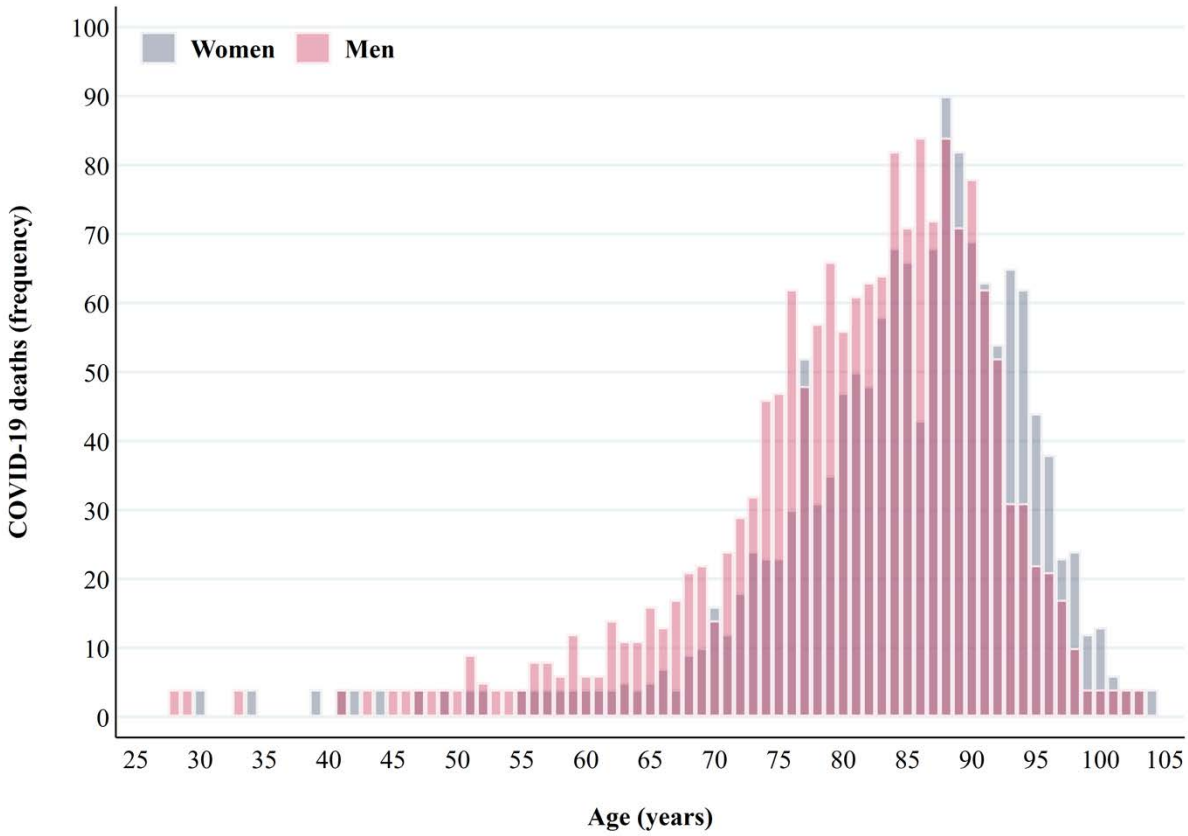
Supplementary Figure 1: COVID-19 deaths reported up to May 7, 2020 (3,122) by days since first COVID-19 death in Sweden on March 5, 2020



Supplementary Figure 2: COVID-19 deaths up to May 7, 2020 (3,122) by single age and sex in Sweden




*Notes: single ages with less than 5 deaths are set to a value of 4 in order to meet the confidentiality requirements of the data provider*

Suppl. Table 1: Deaths and Exposure time to the risk at death for men and women in Sweden

| | Women | | Men | |
|---|---|---|---|---|
| | Deaths | Exposure Time in Years | Deaths | Exposure Time in Years |
| **Civil Status** | | | | |
| Never Married | 136 | 456,590 | 211 | 562,845 |
| Married | 259 | 570,581 | 773 | 577,801 |
| Separated/Divorced | 295 | 195,740 | 303 | 149,827 |
| Widowed | 752 | 111,908 | 396 | 34,085 |
| **Education** | | | | |
| Primary | 620 | 202,974 | 604 | 232,398 |
| Secondary | 518 | 553,676 | 665 | 621,025 |
| Post-Second | 228 | 559,306 | 349 | 446,119 |
| Missing | 76 | 18,862 | 65 | 25,014 |
| **Disposable Income** | | | | |
| Tertile 1 (Low) | 1,109 | 519,394 | 881 | 365,920 |
| Tertile 2 | 235 | 476,432 | 588 | 411,924 |
| Tertile 3 (High) | 98 | 338,992 | 214 | 546,714 |
| **Country of birth** | | | | |
| Sweden | 1,136 | 1,059,960 | 1,269 | 1,055,260 |
| HIC | 182 | 94,034 | 181 | 86,150 |
| LMIC | 124 | 180,825 | 233 | 183,147 |
| **County of residence** | | | | |
| Other | 706 | 1,030,726 | 862 | 1,027,326 |
| Stockholm | 736 | 304,093 | 821 | 297,231 |
| Total[1] | 1,442 | 1,334,819 | 1,683 | 1,324,557 |

[1]Sum of exposure time over all categories may not always add up to the total because of rounding

Suppl. Table 2: Hazard ratios of dying from COVID-19 for men and women in Sweden (age adjusted)

| | Model 1<br>Men | Model 2<br>Women | Model 3<br>Age<66 | Model 4<br>Age>=66 |
|---|---|---|---|---|
| **Sex** | | | | |
| Men | | | 3.04*** | 2.02*** |
| | | | [2.18,4.23] | [1.86,2.18] |
| Women (ref.) | | | 1.000 | 1.000 |
| **Civil Status** | | | | |
| Never Married | 1.49*** | 2.02*** | 1.49* | 1.63*** |
| | [1.27,1.74] | [1.64,2.50] | [1.05,2.12] | [1.43,1.87] |
| Married (ref.) | 1.00 | 1.00 | 1.00 | 1.00 |
| Seperated/Divorced | 1.42*** | 1.78*** | 0.93 | 1.60*** |
| | [1.24,1.62] | [1.50,2.11] | [0.62,1.38] | [1.44,1.78] |
| Widowed | 1.50*** | 1.53*** | 1.19 | 1.46*** |
| | [1.32,1.71] | [1.31,1.78] | [0.43,3.28] | [1.32,1.61] |
| **Education** | | | | |
| Primary | 1.23** | 1.48*** | 2.63*** | 1.29*** |
| | [1.07,1.42] | [1.25,1.75] | [1.66,4.18] | [1.15,1.44] |
| Secondary | 1.24** | 1.36*** | 2.24*** | 1.25*** |
| | [1.08,1.42] | [1.16,1.60] | [1.47,3.41] | [1.13,1.39] |
| Post-Second (ref.) | 1.00 | 1.00 | 1.00 | 1.00 |
| **Disposable Income** | | | | |
| Tertile 1 (Low) | 1.76*** | 1.25* | 5.21*** | 1.35*** |
| | [1.49,2.09] | [1.00,1.57] | [3.38,8.02] | [1.18,1.55] |
| Tertile 2 | 1.53*** | 0.92 | 2.02** | 1.15 |
| | [1.30,1.80] | [0.73,1.17] | [1.27,3.22] | [0.99,1.32] |
| Tertile 3 (ref.) | 1.00 | 1.00 | 1.00 | 1.00 |
| **Country of birth** | | | | |
| Sweden (ref.) | 1.00 | 1.00 | 1.00 | 1.00 |
| HIC | 1.19* | 1.08 | 1.05 | 1.14* |
| | [1.01,1.39] | [0.92,1.26] | [0.61,1.80] | [1.01,1.28] |
| LMIC | 2.56*** | 1.66*** | 2.50*** | 2.14*** |
| | [2.18,3.01] | [1.32,2.09] | [1.76,3.55] | [1.85,2.47] |
| **County of residence** | | | | |
| Other (ref.) | 1.00 | 1.00 | 1.00 | 1.00 |
| Stockholm | 4.50*** | 4.70*** | 3.90*** | 4.60*** |
| | [4.07,4.98] | [4.22,5.24] | [2.91,5.22] | [4.26,4.97] |
| Failures | 1683 | 1442 | 191 | 2934 |
| Time at risk in Years | 1,324,557 | 1,334,819 | 1,977,625 | 681,751 |

Exponentiated coefficients; 95% confidence intervals in brackets; Education variable also includes missing category.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Suppl. Table 3: Hazard ratios of dying from COVID-19 for men and women in Sweden (age adjusted)

| | Model 5 Sex | Model 6 Marital status | Model 7 Education | Model 8 Disp. income | Model 9 Country of birth | Model 10 County of residence |
|---|---|---|---|---|---|---|
| **Sex** | | | | | | |
| Men | 1.73*** | | | | | |
| | [1.61,1.86] | | | | | |
| Women (ref.) | 1.00 | | | | | |
| **Civil Status** | | | | | | |
| Never Married | | 1.60*** | | | | |
| | | [1.42,1.81] | | | | |
| Married (ref.) | | 1.00 | | | | |
| Separated/Divorced | | 1.54*** | | | | |
| | | [1.39,1.70] | | | | |
| Widowed | | 1.10* | | | | |
| | | [1.00,1.21] | | | | |
| **Education** | | | | | | |
| Primary | | | 1.14* | | | |
| | | | [1.03,1.26] | | | |
| Secondary | | | 1.21*** | | | |
| | | | [1.10,1.34] | | | |
| Post-Second (ref.) | | | 1.00 | | | |
| **Disposable Income** | | | | | | |
| Tertile 1 (Low) | | | | 1.22** | | |
| | | | | [1.07,1.38] | | |
| Tertile 2 | | | | 1.24** | | |
| | | | | [1.09,1.42] | | |
| Tertile 3 (ref.) | | | | 1.00 | | |
| **Country of birth** | | | | | | |
| Sweden (ref.) | | | | | 1.00 | |
| HIC | | | | | 1.52*** | |
| | | | | | [1.36,1.70] | |
| LMIC | | | | | 3.49*** | |
| | | | | | [3.11,3.91] | |
| **County of residence** | | | | | | |
| Other (ref.) | | | | | | 1.00 |
| Stockholm | | | | | | 4.49*** |
| | | | | | | [4.18,4.81] |
| Failures | 3125 | 3125 | 3125 | 3125 | 3125 | 3125 |
| Time at risk in Years | 2,659,376 | 2,659,376 | 2,659,376 | 2,659,376 | 2,659,376 | 2,659,376 |

Exponentiated coefficients; 95% confidence intervals in brackets
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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