Patterns of COVID-19 pandemic dynamics following deployment of a broad national immunization program

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Abstract

Studies on the real-life impact of the BNT162b2 vaccine, recently authorized for the prevention of coronavirus disease 2019 (COVID-19), are urgently needed. Here, we analysed the temporal dynamics of the number of new COVID-19 cases and hospitalization in Israel following a vaccination campaign initiated on December 20th, 2020. We conducted a retrospective analysis of data originating from the Israeli Ministry of Health (MOH) from March 2020 to February 2021. In order to distill the possible effect of the vaccinations from other factors, including a third lockdown imposed in Israel on January 2021, we compared the time-dependent changes in number of COVID-19 cases and hospitalizations between (1) individuals aged 60 years and older, eligible to receive the vaccine earlier and younger individuals (0-59 years old); (2) early-vaccinated cities compared to late-vaccinated cities; (3) early-vaccinated geographical statistical areas (GSAs) compared to late-vaccinated GSAs; and (4) the current lockdown versus the previous lockdown, imposed on September 2020. By February 6th 2021, 45.3% and 29.7% of the entire Israeli population (89.9% and 80% of individuals older than 60 years old) received the first dose or both doses of the vaccine, respectively, or recovered from COVID-19. In mid-January, the number of COVID-19 cases and hospitalization started to decline, with a larger and earlier decrease among older individuals. This trend was more evident in early-vaccinated compared to late-vaccinated cities. Such a pattern was not observed in the previous lockdown. Our analysis demonstrates evidence for the real-life effectiveness of a national vaccination campaign in Israel on the pandemic dynamics. This report reflects a snapshot of a fast-changing situation. However, we believe our findings have major public health implications in the struggle against the COVID-19 pandemic, including the public’s perception of the need for and benefit of nationwide vaccination campaigns. More studies aimed at assessing the effectiveness of vaccination both on the individual and on the population level, with larger followup are needed.

Introduction

An effective and safe vaccination campaign is urgently needed to halt the rapid spread of *Severe acute respiratory syndrome coronavirus 2* (SARS-CoV-2) infections and the resulting disease, Coronavirus disease 2019 (Covid-19). The BNT162b2 vaccine, developed by BioNTech in cooperation with Pfizer, is a lipid nucleoside-modified RNA (modRNA) encoding the SARS-CoV-2 full-length spike [1]. On December 11, 2020, the Food and Drug Administration (FDA) issued an Emergency Use Authorization (EUA) for emergency use of the vaccine for the prevention of COVID-19 [2]. Results from a phase III randomized placebo-controlled trials demonstrated that a two-dose regimen in a 21 days interval conferred 95% protection against Covid-19 in individuals 16 years of age or older [3].

On December 20th 2020, Israel launched its COVID-19 vaccination campaign [4], in which BNT162b2 vaccines were administered. In the early phases of the distribution process, individuals considered as being at high risk for COVID-19 were given a priority in vaccination, including individuals older than 60 years old, nursing home residents, healthcare workers, and patients with severe comorbidities. The vaccination campaign was further expanded for individuals aged 55 years old [5] and 40 years old [6] or older, on January 12th and January 19th respectively. While up to the 21st of January vaccine prioritization rollout was mainly by age, following that date pupils aged 16-18 years old were also prioritized for vaccination. On the 28th of January, the vaccination campaign expanded for those aged 35 and older [7]. On the 4th of February, all individuals aged 16 years old and older were eligible to receive the vaccine. However, the HMOs were still instructed to focus their efforts on those aged 50 years old and older [8]. Individuals with a history of severe allergic reactions to the vaccine components, recovered COVID-19 patients or those younger than 16 years of age (with the exception of children with severe chronic diseases) are not eligible to receive the vaccine as of 6th of February.

The national vaccination campaign has led Israel to be the country with the highest rate of vaccinated individuals per capita, with 45.3% and 29.7% of the population having received the first or the second vaccine dose, respectively, or recovered from COVID-19, to date (February 6, 2021). In parallel, during the early weeks of the vaccination campaign, the number of cases and hospitalized patients has rapidly increased, along with the local emergence of the B117 variant [9], leading the government to impose a third lockdown on 8th of January 2021.

Assessing the real-life effect of the vaccines, in order to show that the high efficacy observed under ideal clinical trial conditions is also seen in routine care, is highly important. This can be analysed by either assessing the real-life impact of vaccination programmes at a population level (termed "vaccine impact" (VI)) or by assessing the direct protective effect of the vaccine at the individual level (termed "vaccine effectiveness" (VE)) [10]. On the individual level, a first report from one of the largest Israeli health maintenance organizations (HMO's) concluded an effectiveness of 51% for the first dose of BNT162b2 vaccine after 13-24 days in a real-life setting [11]. However, to our knowledge, no study thus far has studied the impact of the vaccination campaign on the population level and its effect on the patterns of pandemic dynamics. As Israel is one of the first countries to implement a vaccination campaign on this magnitude, we believe that this quantification may be of major interest for many countries worldwide.

Methods

We conducted a retrospective analysis on data from March 2020 to February 2021, originating from the Israeli Ministry of Health (MOH), that included information on age, sex, date of positive SARS-CoV-2 polymerase chain reaction (PCR) test, date of hospitalization, clinical state during hospitalization and date of death for each individual. Data on national vaccination is available online (http://data.gov.il/dataset/covid-19/) and includes the number of daily vaccine doses, separated to first and second doses, administered in each city by age groups (a scale of 10 years). A total of 3,425,684 vaccinated and 684,694 PCR positive individuals were included in the analysis.

In order to assess the real life effectiveness of the vaccine on the national level, we made the following comparisons: First, we compared between individuals aged 0-59 years old with individuals aged 60 years and older, who comprise most of the population prioritized to receive the vaccine earlier. Second, we compared between cities with a high percentage of individuals who were vaccinated early to cities with a low percentage: For every city with more than 5,000 residents aged 60 and older we calculated the percentage of these individuals who received the first dose of the vaccine. We defined *early-vaccinated cities* to be the cities where at least 85% individuals older than 60 years were either vaccinated or recovered from COVID-19 by the 10th of January 2021 (15 cities with a total population of 887,587). We defined *late-vaccinated cities* to be the cities where less than 70% of individuals older than 60 years were vaccinated by the 10th of January 2021 (8 cities with a total population of 1,730,604), see Fig. S7.

Third, we used data with a higher geographical-resolution termed geographical statistical areas (GSAs). The GSAs are small, relatively homogeneous intra-city units defined by the Israeli Bureau of Statistics, with an average of 3,000 residents, within cities with more than 10,000 inhabitants. Data on vaccination for the GSAs was available without age group separation, though the national vaccination policy described earlier still holds information regarding the timing of each age-group's vaccination. Out of 1385 GSAs, 1148 had more than 500 residents aged 60 years and older. Out of these 1148 GSAs, we denoted the 400 with the highest vaccination rate by January 10th, 2021 as *early-vaccinated GSAs* and the 400 with the lowest vaccination rate by January 10th, 2021 as *late-vaccinated GSAs*.

Finally, we compared between the decline in the number of cases and hospitalizations observed following the initiation of the second national lockdown imposed by the Israeli government on

18th of September 2020, and the decline observed following the initiation of the third national lockdown, imposed on the 8th of January 2021. This comparison was done both nationally and by cities and GSAs.

For each of these comparisons, we analysed the temporal changes in weekly numbers of several clinical measures: positive COVID-19 cases, hospitalized patients, hospitalized patients in a moderate and severe state, and hospitalized patients in a severe state. Covid-19 cases were identified by a positive SARS-CoV-2 polymerase chain reaction (PCR) test. Classification of the hospitalization severity was based on the following clinical criteria, applied on 13 of July 2020 by the Israeli MOH[12] based on NIH [13] and WHO[14] definitions: *Mild illness* - individuals who have any of the various signs and symptoms of COVID 19 (e.g., fever, cough, malaise, loss of taste and smell); *Moderate illness* - individuals who have evidence of pneumonia by a clinical assessment or imaging; *Severe illness* - individuals who have respiratory rate >30 breaths per minute, SpO2 <93% on room air at sea level, or ratio of arterial partial pressure of oxygen to fraction of inspired oxygen (PaO2/FiO2) <300 mmHg and *Ventilated/Critical* - individuals with respiratory failure who require ventilation (invasive or non-invasive), multiorgan dysfunction or shock. In our analyses here, we denote all patients in a severe case or worse as severe (including ventilated and critical patients). For the national level, and for each clinical measure, an analysis of the percentage of people over 60 years old from all ages is also analyzed.

Next, we calculated relative changes of these clinical measures at certain dates compared to their respective values at 14, 21, and 28 days earlier. National level changes were reported based on the entire population data, and were shown across all dates since the 3rd lockdown, as well as the last available date explicitly. Changes at the city level were reported for the last available date. The standard deviations of the relative changes were calculated based on 500 bootstrap samples within early-vaccinated and late-vaccinated GSAs.

Results

We first analysed the number of COVID-19 cases and the percentage of vaccinated individuals in Israel. Starting on the 20th of December 2020, the initiation of the vaccination campaign, the number of vaccines administered per day began at approximately 50,000, quickly rose to over 150,000 by December 24th 2020, and reached a maximum of 231,010 on January 21st 2021 (Fig 1). Vaccinations per day for each age group are shown in the supplementary material (SM) (Fig S1). By January 7th, 75% of the population over 60 years old have already been vaccinated (1st dose) or recovered, increasing gradually to 89.9% (1st dose) and 80% (both doses) by February 6th 2021.

We next analysed the temporal changes in the number of new COVID-19 cases and hospitalizations in Israel from December 18th to February 6th (Fig 2, 4). Several days after the initiation of the lockdown on January 8th and the beginning of the administration of the second vaccine doses on January 10th, the number of new COVID-19 cases aged 60 years old and older reached a peak. This peak was followed by a peak in moderate or severe hospitalization of individuals, and a later peak in severe hospitalization of the same age group. Between January 15 and February 6 the number of new cases and hospitalizations in this age group started to decline. As several potential factors may have influenced this decline, we performed several analyses aimed at estimating the potential role of the vaccination campaign:

We first compared between individuals aged 0-59 years old and individuals 60 years and older, who were prioritized to receive the vaccine earlier (Table 1, Fig. 2). Notably, the decrease in number of cases and hospitalizations was larger and earlier in older individuals compared to younger individuals, who were only recently eligible to receive the vaccine. For example, a decrease of approximately -49% in cases, -36% in hospitalizations and -29% in severe hospitalizations were observed compared to 21 days before February 6th for individuals 60 years and older; while for individuals aged 0-59 years, a smaller decrease of -18% in cases and an increase of 10.5% hospitalizations and 32% severe hospitalizations were observed.

Next, we compared between *early-vaccinated* cities and *late-vaccinated* cities (see Methods). This analysis revealed a larger and earlier decrease in the number of COVID-19 cases and hospitalizations of individuals 60 years old and older in cities vaccinated early compared to late-vaccinated cities. For example, in early-cities, there was a decrease of -60% in cases and -37% in severe hospitalizations compared to 21 days before February 6th, while in late-cities a smaller decrease of -36% in cases and -17% in severe hospitalizations was observed. Third, in order to obtain a higher geographic resolution we compared between *early-vaccinated* GSAs and *late-vaccinated* GSAs (see Methods) (Table 2, Fig. 4). This analysis revealed the same findings as the city level analysis.

Finally, we compared between the decrease in number of cases and hospitalizations observed following the second national lockdown imposed by the Israeli government on 18th of September 2020, and the dynamics observed following the third national lockdown, imposed on the 8th of January 2021. The larger decline in older individuals (age above 60 years old) compared to younger individuals (0-59 years old) was only apparent in the third lockdown (Fig. 3).

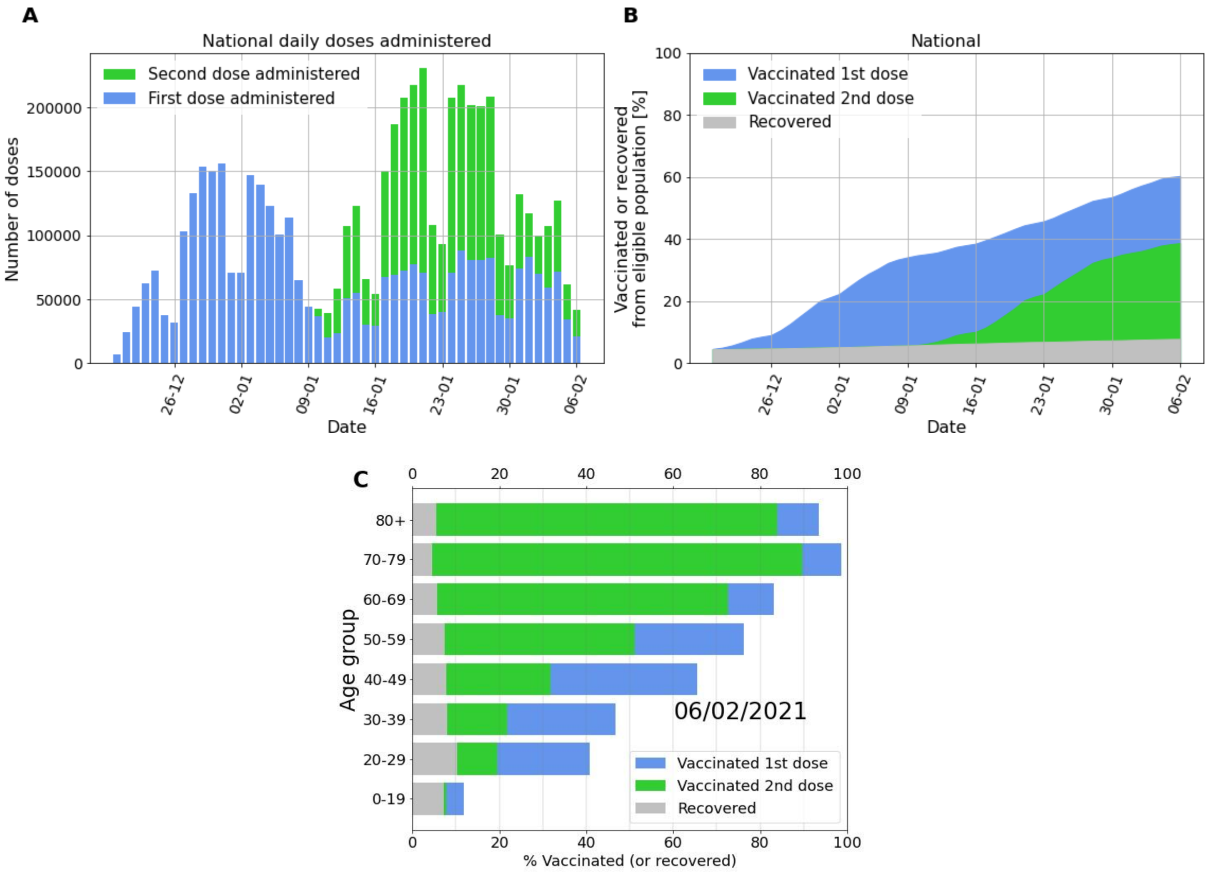

Fig. 1. **A.** Daily national number of administered vaccination doses, first dose (blue bars) and second dose (green bars). **B.** Cumulative percentage of the national population recovered or vaccinated. Vaccinated population that received the first dose is shown in blue; vaccinated population that received the second dose is shown in green. Recovered population is shown in gray. **C.** Vaccinated or recovered percentage per age group.

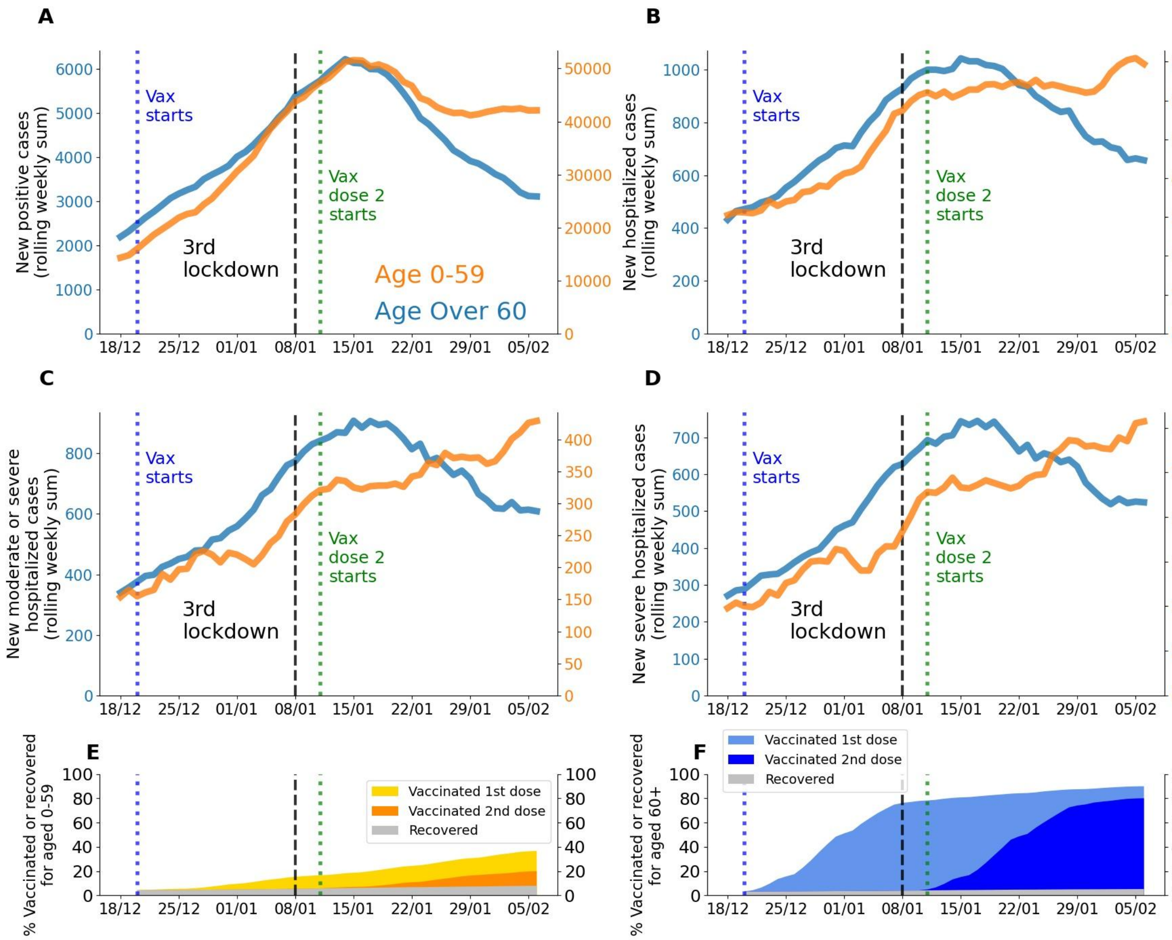

Fig. 2. Comparison between the population aged 0-59 years old (orange line in A-D) and the population aged 60 years old and older (blue line in A-D) during the vaccination period, on a nationwide level. In all figures the vaccination campaign start date is shown as a vertical dotted blue line, the start date for second vaccination dose is shown as a vertical dotted green line and the third lockdown start date is shown as a dashed black line. Note: Figures A-D are presented with 2 different y-axis scales in order to highlight relative within-population trends. **A.** Rolling weekly sum of new positive cases (Orange: N=273,020, Blue: N=31,368). **B.** Rolling weekly sum of new mild, moderate or severe hospitalizations (Orange: N=3,892, Blue: N=5,707). **C.** Rolling weekly sum of new moderate or severe hospitalizations (Orange: N=4,856, Blue: N=2,118) **D.** Rolling weekly sum of new severe hospitalizations (Orange: N=1,485, Blue: N=3,991). **E.** Cumulative percentage of age group 0-59 years old population recovered or vaccinated. Vaccinated population after the first dose is shown in yellow, vaccinated population after the second dose is shown in orange and recovered population is shown in gray. **F.** Cumulative percentage of the 60+ years old population who are recovered or vaccinated. Vaccinated population after the first dose is shown in light blue, vaccinated population after the second dose is shown in blue and recovered population is shown in gray.

Group	Age group, years	% change from		
		14 days back	21 days back	28 days back
New cases	0-59	-5.2	-18.2	-5.6
New cases	60+	-36.4	-49.2	-43.4
New Hospitalizations:				
Mild, Moderate or Severe	0-59	8.8	10.5	16.1
Mild, Moderate or Severe	60+	-29.7	-36.3	-32
Moderate or Severe	0-59	24.3	33.2	43.5
Moderate or Severe	60+	-26.8	-31.2	-24.4
Severe	0-59	26.3	32.3	52.7
Severe	60+	-22.9	-28.6	-19.5

Table 1. National percent change of COVID-19 cases and hospitalizations, calculated between the weekly sum on February 6th and the respective weekly sums 14, 21, 28 days earlier.

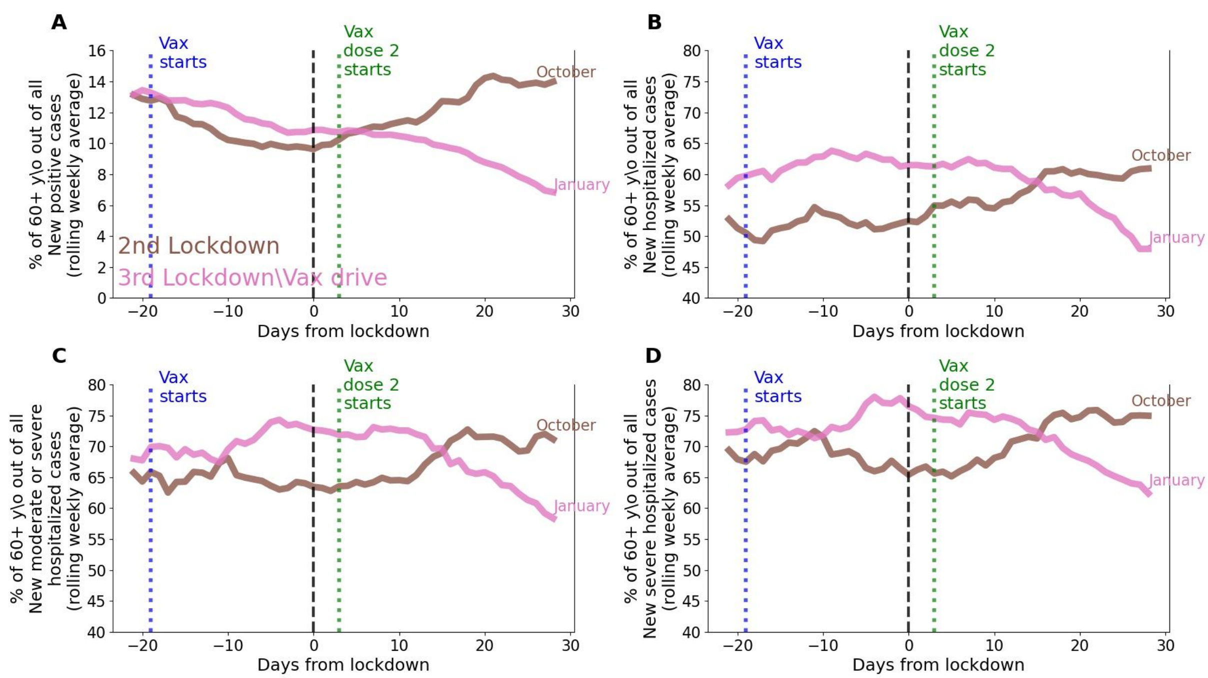

Fig. 3. Percentage of people over 60 years old from all ages before and after the 2nd lockdown (brown line) and 3rd lockdown (pink line). Lockdown start date for both lockdowns is "Day 0" and is shown as a dashed black line. Vaccination start date is shown relative to the 3rd lockdown start as a blue dotted line (first dose) and as green dotted line (second dose). **A.** New cases. **B.** New mild, moderate or severe hospitalizations. **C.** new moderate or severe hospitalizations **D.** New severe hospitalizations.

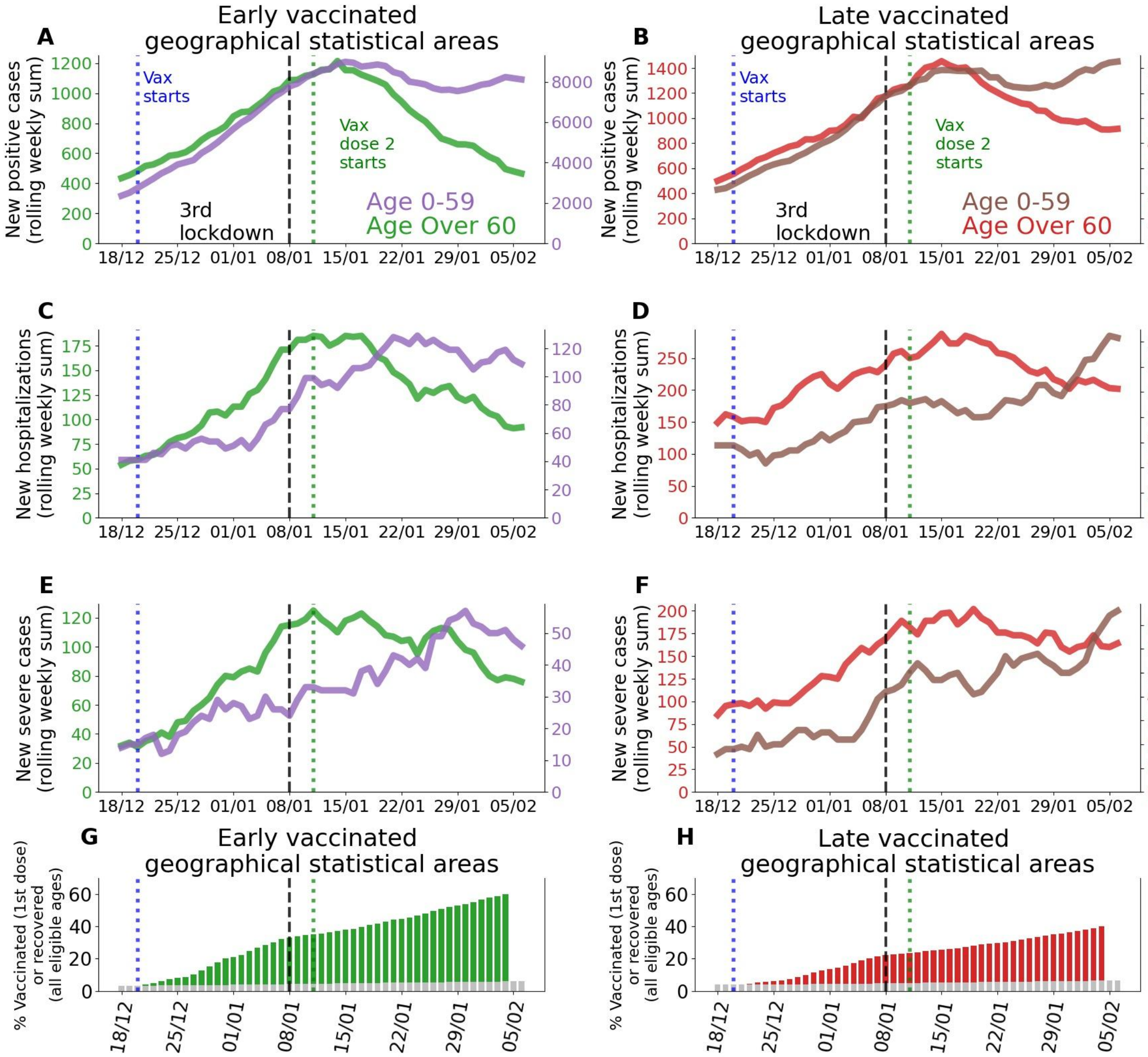

Fig 4. Comparison between age groups 0-59 years old and 60+ years old from early- and late-vaccinated GSAs. In all figures the initiation of the vaccination campaign is shown as a dashed purple line, the third lockdown start date is shown as a dashed black line and the date in which individuals have started to receive the 2nd dose of the vaccine is marked as a dashed green line. Note: Figures A-F are presented with different y-axis scales in order to highlight relative within-population trends. Age group 0-59 is shown as a purple line in A,C,E and as a brown line in B,D,F. Age group 60+ is shown as a green line in A,C,E and as a red line in B,D,F. **A.** Rolling weekly sum of new positive cases in early-vaccinated GSAs (Purple: N=49,253, Green: N=5,888). **B.** Rolling weekly sum of new positive cases in late-vaccinated GSAs (Brown: N=39,181, Red: N=7,394). **C.** Rolling weekly sum of new mild, moderate or severe hospitalizations in early-vaccinated GSAs (Purple: N=629, Green: N=914). **D.** Rolling weekly sum of new mild, moderate or severe hospitalizations in late-vaccinated GSAs (Brown: N=763, Red: N=1,619). **E.** Rolling weekly sum of new severe hospitalizations in early-vaccinated GSAs (Purple: N=242, Green: N=638). **F.** Rolling weekly sum of new severe hospitalizations in late-vaccinated GSAs (Brown: N=294, Red: N=1,106). **G.** Percentage of individuals vaccinated or recovered in time in early-vaccinated GSAs. **H.** Percentage of individuals vaccinated or recovered in time in late-vaccinated GSAs.

Group	Age group, years	% change from					
		14 days back		21 days back		28 days back	
		Early GSAs	Late GSAs	Early GSAs	Late GSAs	Early GSAs	Late GSAs
New cases	0-59	1.4 (4.6)	14.5 (4.3)	-9.2 (4.0)	5 (4.9)	2.6 (4.6)	20.9 (5.4)
New cases	60+	-47.5 (3.5)	-21.8 (4.3)	-59.5 (2.4)	-35.6 (3.6)	-57.2 (3.1)	-25.4 (4.6)
New Hospitalizations:							
Mild, Moderate or Severe	0-59	-11.4 (12.5)	53 (21.0)	2.8 (15.1)	62.7 (22.2)	26.7 (21.0)	58.4 (19.3)
Mild, Moderate or Severe	60+	-32.4 (8.6)	-21.1 (7.7)	-50 (6.6)	-26 (7.4)	-49.2 (7.5)	-21.4 (7.7)
Severe	0-59	15 (26.3)	33.3 (26.1)	48.4 (36.0)	55.1 (30.0)	58.6 (43.0)	76.7 (37.4)
Severe	60+	-27.6 (10.6)	-6.8 (10.0)	-36.7 (10.1)	-17.2 (8.5)	-34.5 (10.7)	-8.4 (10.3)

Table 2. Percent change of COVID-19 cases and hospitalizations in early- and late-vaccinated Geographical Statistical Areas (GSAs), calculated between the weekly sum on February 6th and the respective weekly sums 14, 21, 28 days earlier.

Discussion

Here we show early signs for the effect of a national vaccination campaign in Israel on the pandemic dynamics. Our analysis revealed that in the past week, approximately one and a half month after the initiation of the vaccination campaign, with 80% of individuals older than 60 years old already vaccinated (February 6th, 2021), there was an approximately 49% drop in number of cases, 36% drop in COVID-19 related hospitalizations and 29% drop in critically ill patients compared to 21 days ago. Although multiple other factors may have influenced these results, several observations suggest that these patterns are driven to a considerable degree by the vaccines. First, the decline in the measures above is greater in older individuals who were prioritized to receive the vaccine earlier. Second, the effect was greater in cities and GSAs where a higher fraction of individuals were vaccinated earlier. Finally, we did not observe similar dynamics in the previous lockdown imposed in Israel (SM. Figs S3, S4, S5, S6, S9 & S10).

Notably, although previous reports have indicated that efficacy of the vaccine is already evident after the first dose [3,11], the improvement in the number of new cases and hospitalized patients has occurred only 21 days following the vaccination campaign. We believe that this has several reasons. First, the effect of vaccines in real-life may take longer than demonstrated in clinical trials due to numerous reasons. For example, the logistics of refrigeration, storage, transportation and on-site administration of the vaccines in real-world settings and during a rapid deployment campaign may have been imperfect, thus lowering effectiveness. Second, the effect may be heterogeneous and population-dependent. For example, it is possible that older individuals, who were prioritized earlier in the vaccination campaign, may have a reduced or belated response to the vaccination due to a deterioration in both innate and adaptive immune function, also termed immunosenescence, as was previously shown for other vaccines [15,16]. Third, it is possible that the efficacy of the vaccine is reduced in light of the emergence of new and more violent viral strains, such as the B117 variant [17] (which is already prevalent in Israel at February 2021 according to the Israeli MOH), and the 501.V2 variant [18] which may be associated with an increased risk of death [19]. Fourth, it is possible that vaccinated individuals may alter their behaviour and decrease adherence to public health prevention guidance (e.g. physical distancing, face masks) thereby increasing viral transmission. Moreover, viral transmission may also occur in the vaccination sites themselves. The vaccination sites should be large and ventilated in order to decrease the probability of transmission on site. Finally, there is a clear trend where areas in Israel with higher infection rates and a lower socioeconomic status have lower vaccination rates, despite wide vaccine availability [20]. Further effort should be made to encourage these populations to vaccinate and make the vaccines even more easily accessible for them. We note that exact individual-level efficacy numbers cannot be deduced from our analysis, and that due to all of the above issues, our results may be consistent with efficacies that are either lower or greater than those reported in the original clinical trial.

Our study has several limitations. First and foremost, our study is an observational study as opposed to a randomized clinical trial and therefore causal effects are difficult to infer. Second, the comparison between the second and third lockdown may be influenced by factors such as the total number of COVID-19 cases in the beginning of each lockdown, testing policy, hospitalization policy and public compliance to the restrictions that may have changed with time. Similarly, differences between cities might be influenced by behavioral and social differences beyond the vaccines. However, none of these factors were likely to cause the different patterns observed in the different age groups reported here. Finally, the effects of the vaccination campaign observed here may be influenced by factors specific to Israel and its healthcare system, in which all citizens are mandated to join one of the official non-profit health insurance organizations. Financial and regional disparities in other health-care systems may impact the distribution and availability of vaccinations, thereby influencing the real life efficacy of the vaccines.

Overall, we show an analysis of large-scale real-world data from Israel demonstrating first signs of real-life effectiveness of a national vaccination campaign, Although our findings are preliminary, they have major public health implications for the struggle against the COVID-19 pandemic. More studies aimed at assessing the effectiveness of the vaccination on reducing the transmission of SARS-CoV- are needed both on the individual and on the population level with larger longitudinal followup and in additional populations.

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Data availability statement

The data that support the findings of this study originates from the Israel ministry of health.
National age-group level vaccination data:
https://data.gov.il/dataset/covid-19/resource/57410611-936c-49a6-ac3c-838171055b1f
Aggregated town-level and age groups vaccination data is available at:
https://data.gov.il/dataset/covid-19/resource/12c9045c-1bf4-478a-a9e1-1e876cc2e182
Aggregated GSA -level infection, hospitalization and vaccination data is available at:
https://data.gov.il/dataset/covid-19/resource/d07c0771-01a8-43b2-96cc-c6154e7fa9bd
Some restrictions apply to the availability of parts of the data used in the analysis and so are not publicly available.

Code availability statement

Any relevant source code will be made available at:
https://github.com/hrossman/Patterns-of-covid-19-pandemic-dynamics-following-deployment-of-a-broad-national-immunization-program

Ethics Declarations

An exemption from institutional review board approval was determined by the Israeli Ministry of Health as part of an active epidemiological investigation, based on use of anonymous data only and no medical intervention.

Competing Interests Statement

The authors declare no competing interests.

Authors contribution

H.R conceived the project, designed and conducted the analyses, interpreted the results and wrote the manuscript; S.S & T. M designed and conducted the analyses, interpreted the results and wrote the manuscript; M.G, U.S, E.S designed the analyses, interpreted the results, wrote the manuscript, supervised and conceived the project.

Acknowledgments

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Supplementary appendix

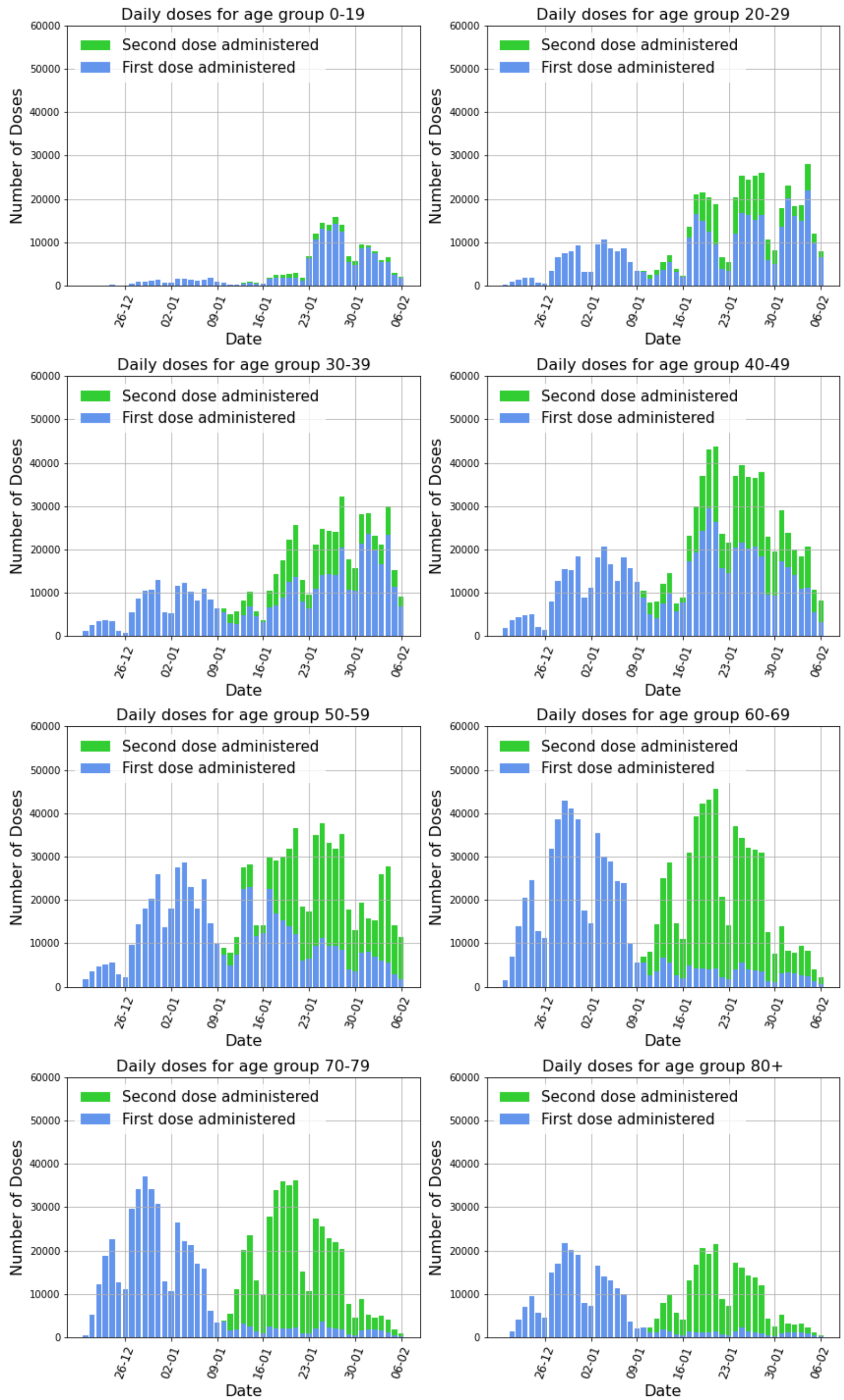

Fig S1. Daily number of administered vaccination doses by age groups, first dose (blue bars) and second dose (green bars).

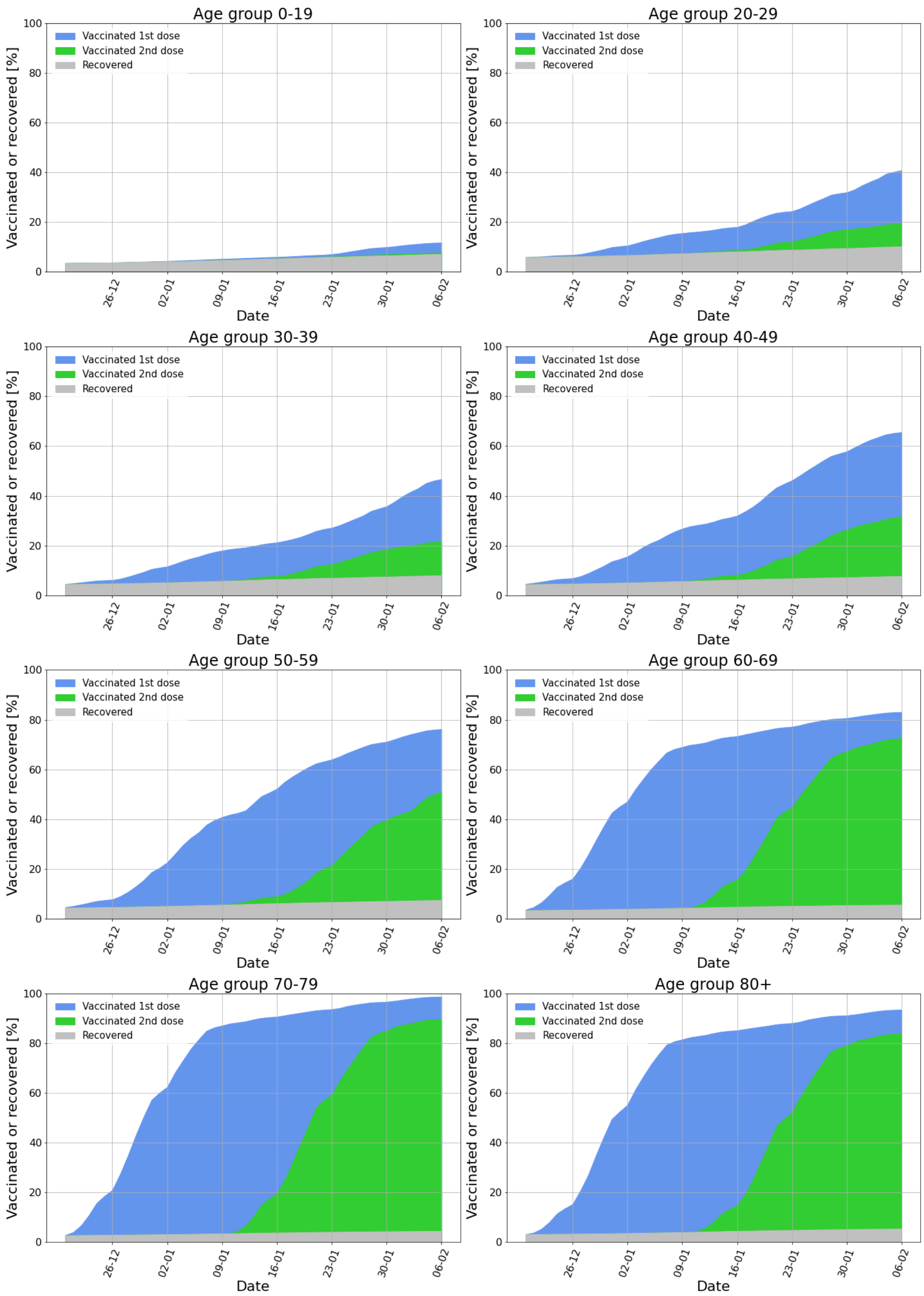

Fig S2. Cumulative percentage of each age-group recovered or vaccinated. Vaccinated population that received the first dose is shown in blue; and the vaccinated population that received the second dose is shown in green. Recovered population is shown in gray.

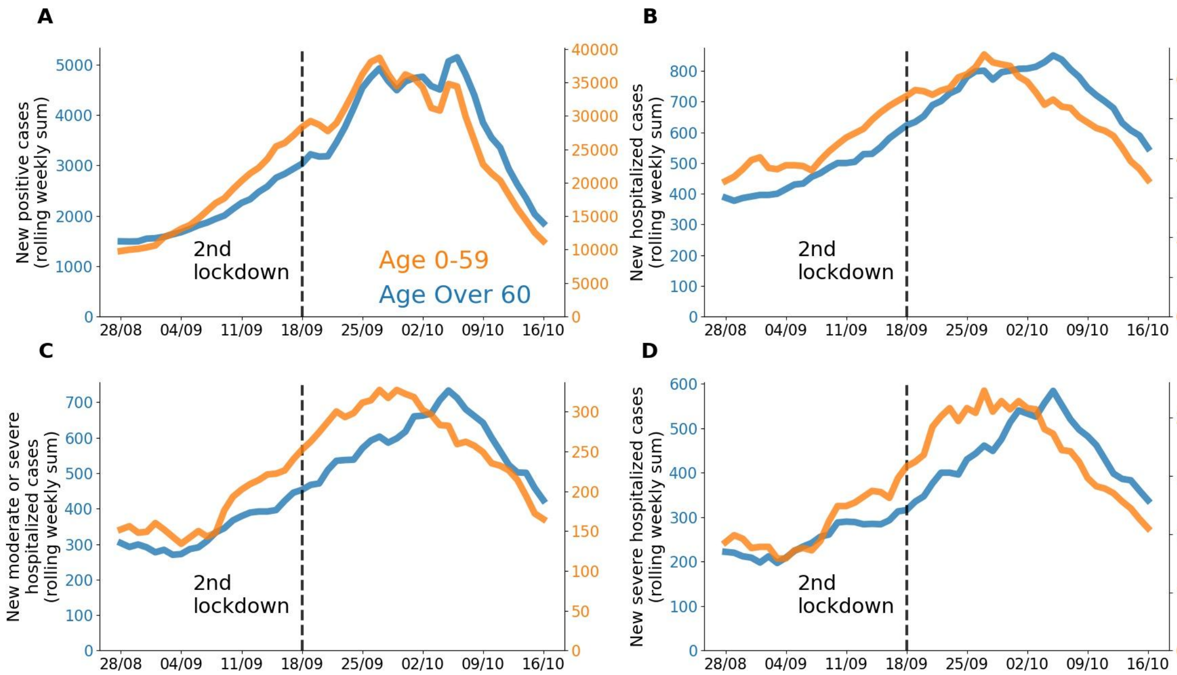

Fig. S3. Comparison between the population aged 0-59 years old (orange line in A-D) and the population aged over 60 years old (blue line in A-D) during a period around the 2nd national lockdown imposed on September 18, 2020. In all figures the 2nd lockdown start date is shown as a dashed black line. Note: Figures A-D are presented with different y-axis scales in order to highlight relative within-population trends. **A.** Rolling weekly sum of new positive cases (Orange: N=167,591, Blue: N=22,104). **B.** Rolling weekly sum of new mild, moderate or severe hospitalizations (Orange: N=3,501, Blue: N=4,427). **C.** Rolling weekly sum of new moderate or severe hospitalizations (Orange: N=1,644, Blue: N=3,400). **D.** Rolling weekly sum of new severe hospitalizations (Orange: N=1,046, Blue: N=2,587).

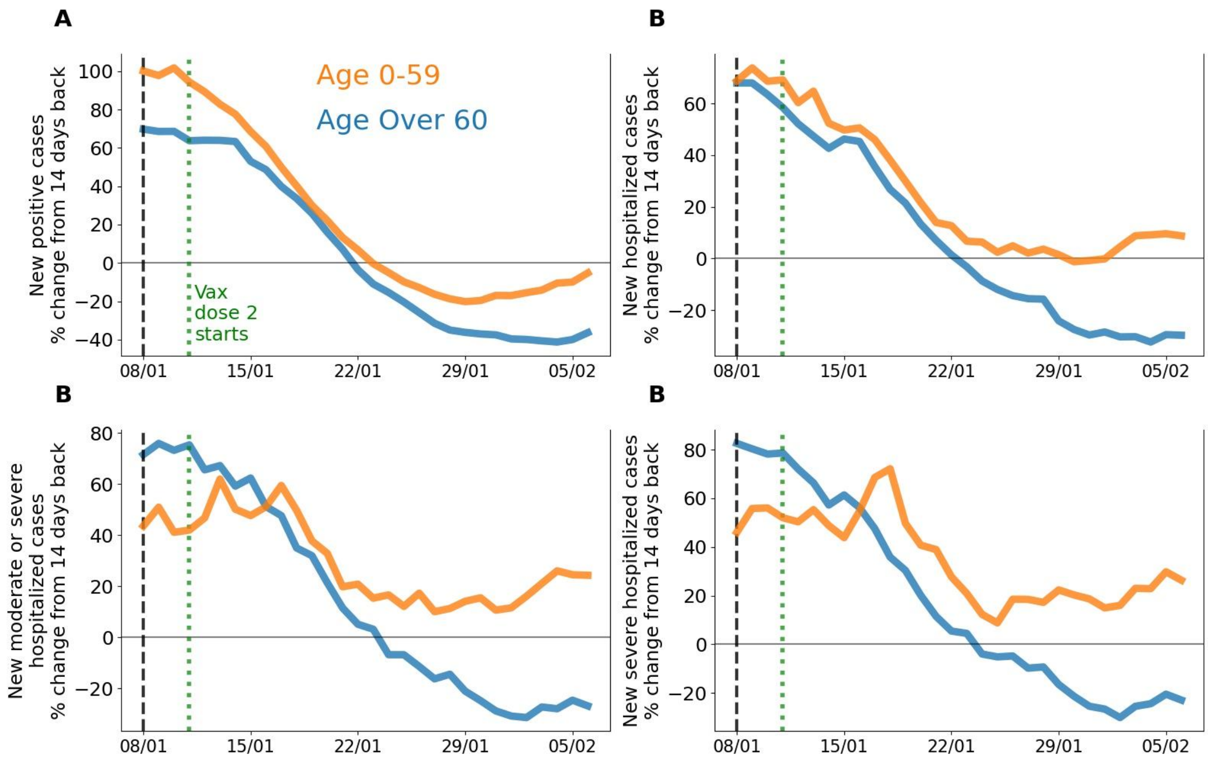

Fig. S4. Comparison of the percent change in cases and hospitalization relative to 14 days between the population aged 0-59 years old (orange line in A-D) and the population aged over 60 years old (blue line in A-D). In all figures the 3rd lockdown start date is shown as a dashed black line and the date in which individuals have started to receive the 2nd dose of the vaccine is shown as a dashed green line. Note: Figures A-D are presented with different y-axis scales in order to highlight relative within-population trends. **A.** Percentage change of the sum of new positive cases in the last 14 days . **B.** Percentage change of the sum of new moderate or severe hospitalizations in the last 14 days. **C.** Percentage change of the sum of new mild, moderate or severe hospitalizations in the last 14 days. **D.** Percentage change of the sum of new severe hospitalizations in the last 14 days.

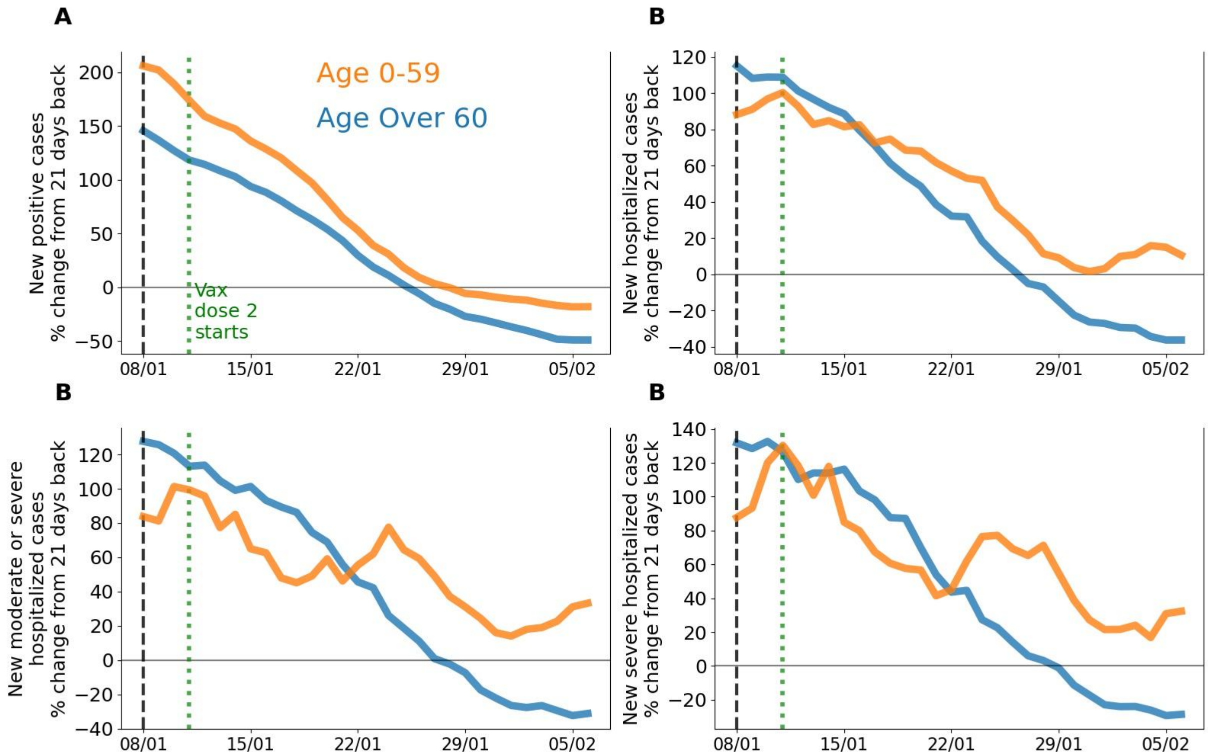

Fig. S5. Comparison of the percent change in cases and hospitalization relative to 21 days between the population aged 0-59 years old (orange line in A-D) and the population aged over 60 years old (blue line in A-D). In all figures the 3rd lockdown start date is shown as a dashed black line and the date in which individuals have started to receive the 2nd dose of the vaccine is shown as a dashed green line. Note: Figures A-D are presented with different y-axis scales in order to highlight relative within-population trends. **A.** Percentage change of the sum of new positive cases in the last 21 days . **B.** Percentage change of the sum of new moderate or severe hospitalizations in the last 21 days. **C.** Percentage change of the sum of new mild, moderate or severe hospitalizations in the last 21 days. **D.** Percentage change of the sum of new severe hospitalizations in the last 21 days.

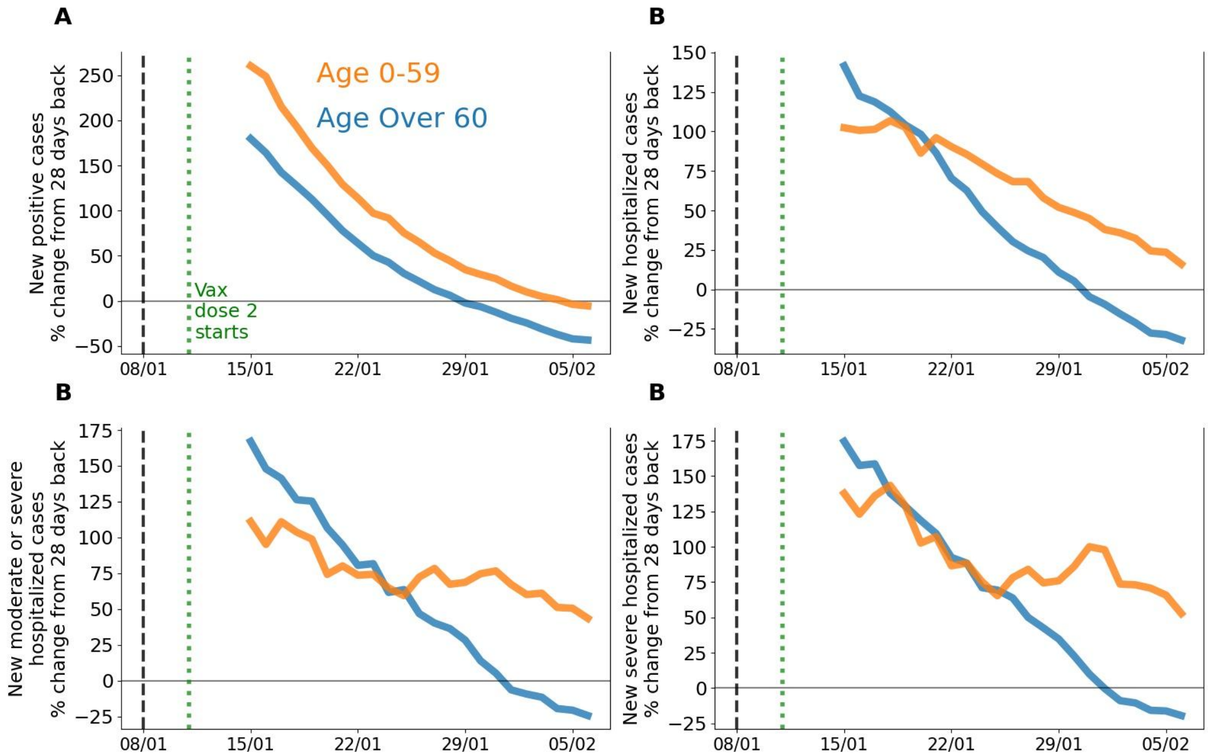

Fig. S6. Comparison of the percent change in cases and hospitalization relative to 28 days between the population aged 0-59 years old (orange line in A-D) and the population aged over 60 years old (blue line in A-D). In all figures the 3rd lockdown start date is shown as a dashed black line and the date in which individuals have started to receive the 2nd dose of the vaccine is marked as a dashed green line. Note: Figures A-D are presented with different y-axis scales in order to highlight relative within-population trends. **A.** Percentage change of the sum of new positive cases in the last 28 days . **B.** Percentage change of the sum of new moderate or severe hospitalizations in the last 28 days. **C.** Percentage change of the sum of new mild, moderate or severe hospitalizations in the last 28 days. **D.** Percentage change of the sum of new severe hospitalizations in the last 28 days.

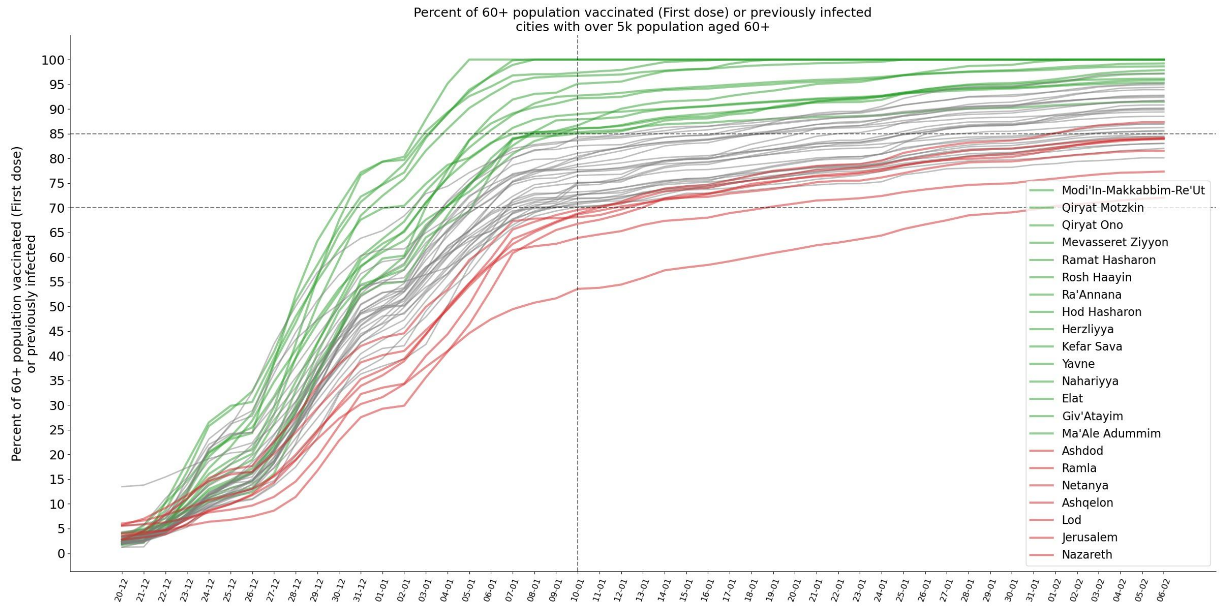

Fig S7. Cumulative percentage of vaccinated population from age group 60+, in cities with more than 5,000 residents in this age group. Early-vaccinated cities are shown as green lines, late-vaccinated cities are shown as red lines. Other cities are shown as gray lines.

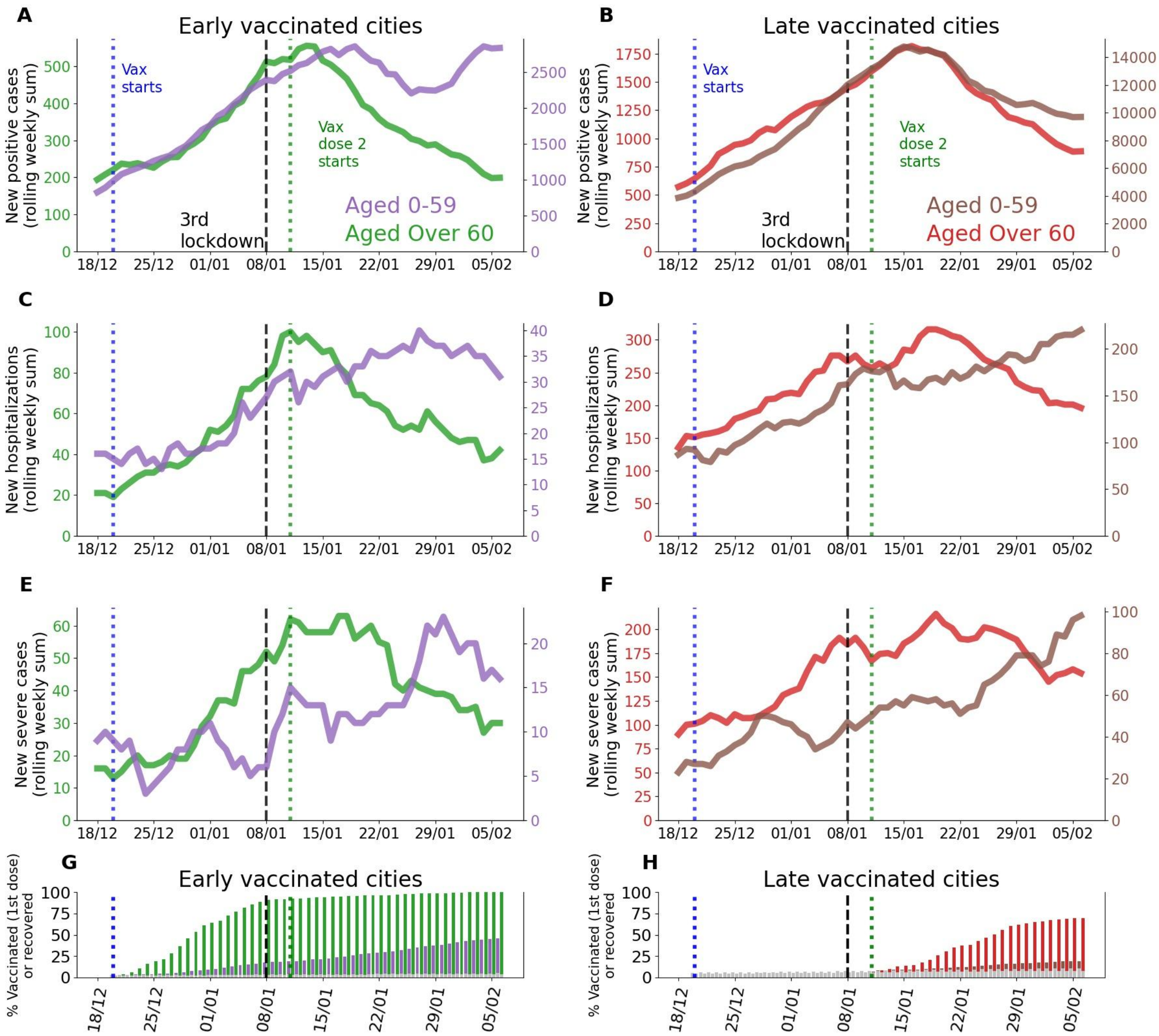

Fig S8. Comparison between age groups 0-59 years old and 60+ years old from cities with most of the population vaccinated early and cities with most of the population vaccinated late. In all figures the vaccination campaign start date is shown as a vertical dotted blue line, the vaccination second dose start date is shown as a vertical dotted green line and the third *hard* lockdown start date is shown as a dashed black line. Note: Figures A-F are presented with 2 different y-axis scales in order to highlight relative within-population trends. Age group 0-59 is shown as a purple line in A,C,E and as a brown line in B,D,F. Age group 60+ is shown as a green line in A,C,E and as a red line in B,D,F. **A.** Rolling weekly sum of new positive cases in early-vaccinated cities (Purple: N=15,528, Green: N=2,497). **B.** Rolling weekly sum of new positive cases in late-vaccinated cities (Brown: N=73,955, Red: N=9,070). **C.** Rolling weekly sum of new mild, moderate or severe hospitalizations in early-vaccinated cities (Purple: N=196, Green: N=409). **D.** Rolling weekly sum of new mild, moderate or severe hospitalizations in late-vaccinated cities (Brown: N=1,112, Red: N=1,713). **E.** Rolling weekly sum of new severe hospitalizations in early-vaccinated cities (Purple: N=85, Green: N=281). **F.** Rolling weekly sum of new severe hospitalizations in late-vaccinated cities (Brown: N=390, Red: N=1,159). **G.** Cumulative percentage of the population recovered or vaccinated (1st dose) in early-vaccinated cities. Age group 60+ is shown as green bars, age group 0-59 is shown as purple bars. Recovered population is shown as gray bars. **H.** Cumulative percentage of the population recovered or vaccinated (1st dose) in late-vaccinated cities. Age group 60+ is shown as red bars and age group 0-59 is shown as brown bars. Recovered population is shown as gray bars.

Group	Age group, years	% change from					
		14 days back		21 days back		28 days back	
		Early cities	Late cities	Early cities	Late cities	Early cities	Late cities
New cases	0-59	14.6	-21.2	0.5	-33.7	19.5	-21.8
New cases	60+	-41.6	-39.1	-60.5	-51.2	-60.8	-40
New Hospitalizations:							
Mild, Moderate or Severe	0-59	-11.4	27.9	-3.1	38.4	3.3	27.2
Mild, Moderate or Severe	60+	-31.1	-33.3	-53.8	-30.7	-50	-29
Severe	0-59	23.1	81.5	77.8	66.1	60	122.7
Severe	60+	-44.4	-18.5	-48.3	-18.9	-38.8	-19.4

Table S1. Percent change of COVID-19 cases and hospitalizations in early- and late-vaccinated cities, calculated between the weekly sum on February 6th and the respective weekly sums 14, 21, 28 days earlier.

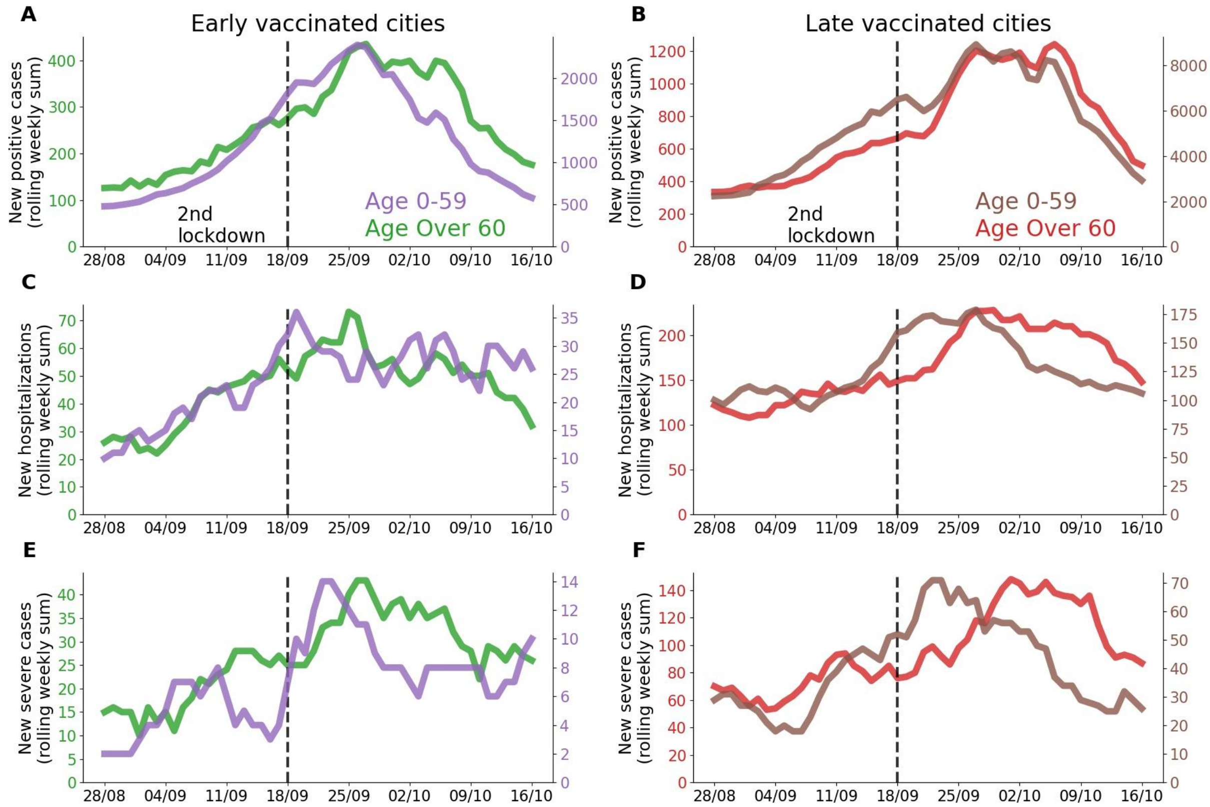

Fig S9. Comparison between age groups 0-59 years old and 60+ years old from cities with most of the population vaccinated early and cities with most of the population vaccinated late. In all figures the second lockdown start date is shown as a dashed black line. Note: Figures A-F are presented with different y-axis scales in order to highlight relative within-population trends. Age group 0-59 is shown as a purple line in A,C,E and as a brown line in B,D,F. Age group 60+ is shown as a green line in A,C,E and as a red line in B,D,F. **A.** Rolling weekly sum of new positive cases in early-vaccinated cities (Purple: N=9,152, Green: N=1,900). **B.** Rolling weekly sum of new positive cases in late-vaccinated cities (Brown: N=39,184, Red: N=5,262). **C.** Rolling weekly sum of new mild, moderate or severe hospitalizations in early-vaccinated cities (Purple: N=172, Green: N=330). **D.** Rolling weekly sum of new mild, moderate or severe hospitalizations in late-vaccinated cities (Brown: N=917, Red: N=1,187). **E.** Rolling weekly sum of new severe hospitalizations in early-vaccinated cities (Purple: N=50, Green: N=192). **F.** Rolling weekly sum of new severe hospitalizations in late-vaccinated cities (Brown: N=292, Red: N=684).

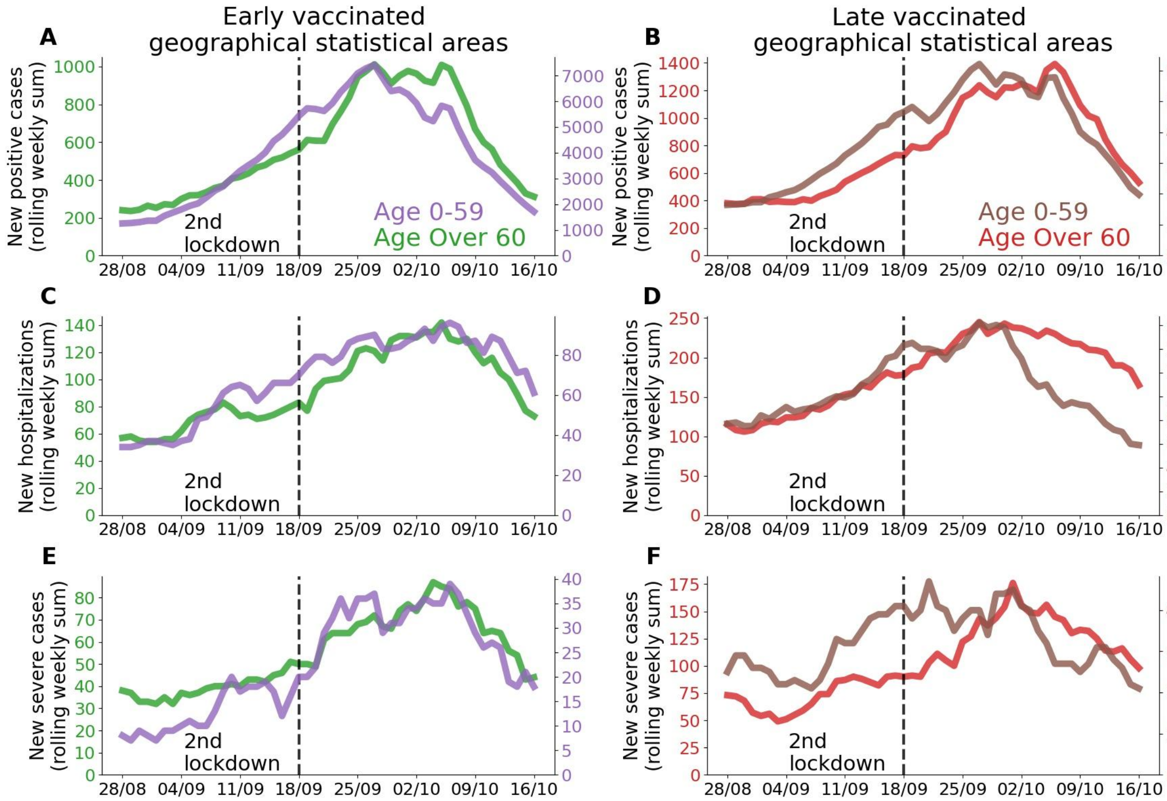

Fig S10. Comparison between age groups 0-59 years old and 60+ years old from geographical statistical areas (GSAs) with most of the population vaccinated early and GSAs with most of the population vaccinated late. In all figures the second lockdown start date is shown as a dashed black line. Note: Figures A-F are presented with different y-axis scales in order to highlight relative within-population trends. Age group 0-59 is shown as a purple line in A,C,E and as a brown line in B,D,F. Age group 60+ is shown as a green line in A,C,E and as a red line in B,D,F. **A.** Rolling weekly sum of new positive cases in early-vaccinated GSAs (Purple: N=29,016, Green: N=4,175). **B.** Rolling weekly sum of new positive cases in late-vaccinated GSAs (Brown: N=27,539, Red: N=5,680). **C.** Rolling weekly sum of new mild, moderate or severe hospitalizations in early-vaccinated GSAs (Purple: N=493, Green: N=669). **D.** Rolling weekly sum of new mild, moderate or severe hospitalizations in late-vaccinated GSAs (Brown: N=775, Red: N=1,301). **E.** Rolling weekly sum of new severe hospitalizations in early-vaccinated GSAs (Purple: N=160, Green: N=392). **F.** Rolling weekly sum of new severe hospitalizations in late-vaccinated GSAs (Brown: N=230, Red: N=737).