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Introduction

The principal goal of this paper is to provide estimates of the total excess mortality experienced in Israel during 2020. By this, I refer to the number of people who have died over and above the number expected in the absence of Covid-19. Over the summer of 2020 there was some debate about the magnitude of excess mortality in Israel, with initial reports denying any general effect (Edrat & Efrati, 2020) or pointing to small effects at particular times (Ashkenazi, 2020; CBS, 2020b), followed by later reports confirming some excess mortality beginning in August (Karlinski, 2020; Less, 2020). None of these reports were comprehensive. Few were systematic. And all erred in at least one, and usually two, ways, corrected here.

This paper also has two secondary goals. The first is to quantify both how this excess mortality varies by age, and the extent to which it has been affected by Israel's age structure. The key point of departure here is that the ratio of young-to-old is much higher in Israel than in most developed countries. Since, irrespective of overall number of deaths from Covid-19, the probability of death from Covid-19 increases geometrically with age (Omori et al., 2020), it has been widely asserted — reasonably so — that more Israelis would have died in this epidemic if: (i) Israel's age structure was closer to that of most developed countries; or (ii) the age-pattern of Covid infection in Israel matched those countries' older age structures. This argument is also consistent with crossnational comparisons of Covid mortality that do not include Israel.

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Dudel et al. (2020), for example, show that the age structure of confirmed cases explains more than two-thirds of cross-national variation in Covid case fatality ratios. Here, using age-standardization procedures, we provide more precise estimates of how many more Israelis would have died under these different age-specific infection scenarios.

The final goal of the paper is to estimate the effects of Israel's 2020 excess mortality on life expectancy. Since the latter is calculated by summarizing the mortality experience across all ages, it provides a simple and direct way to assess how changes in mortality affect the population as a whole. It also allows us to compare Israel's actual mortality experience to expected patterns. For example, researchers have estimated that Covid had already reduced life expectancy at birth by more than one year in the UK up to the end of November (Aburto et al., 2020), and by the beginning of December in the US (Heuveline, 2020). Final estimates for 2020 suggest a loss of life expectancy of 1.13 years in the US, with 3 to 4 times that level among Blacks and Latinos (Andrasfay & Goldman, 2021). More generally, a microsimulation study suggests that each percentage increase in the prevalence of COVID-19 infection in Western Europe, North America or Latin America/Caribbean will reduce life expectancy by about 0.1 years (Marois et al., 2020). Given Israel's infection levels of around 4.5% of the population by the end of 2020, that implies a reduction in life expectancy of almost 5 months. Here we evaluate how close to that estimate Israel is likely to be.

A few main findings emerge from these analyses. First, between March and late December of 2020 there were approximately 10% more deaths than there most likely would have been in the absence of Covid. Contrary to many early reports, some excess mortality can already be seen in April.

Second, the increases in mortality rates were not solely concentrated in the 75+ age group. The proportionate increases in mortality rates were similar at all ages above 55.

Third, confirmed Covid infections in Israel since July were disproportionately among the young and middle-aged. If the age-pattern of infections had been proportionate to Israel's age composition, then assuming the same age-specific case-fatality ratio, the overall number of Covid deaths would have been about 32% higher. If infections had been proportionate to the OECD's age composition — which in Israel's case means disproportionately higher among the elderly — Covid deaths would have doubled.

Finally, Covid-19 reduced life expectancy at birth in Israel in 2020 by about 2.2 months. It reduced expectancy at age 65 by 2.9 months for men and 2.6 months for women. This reversal in the normal upward trend is significant, but it is a smaller reduction than expected and much more modest than in most developed countries outside East Asia and Australasia.

Background

Questions about excess mortality in the Covid-19 epidemic — how many extra deaths it will cause — have been front-and-center in public discussions since the beginning of the epidemic. The number of deaths, alongside associated measures like the case-fatality ratio, is the principal measure of a system's success in managing the epidemic. For this reason, deaths feature prominently on every Covid dashboard, from cross-national collections like those at Johns Hopkins University and the European Centre for Disease Prevention and Control,[1] to national data collection efforts, like Israel's own Covid-related data repository and dashboard.[2]

At first glance, converting an official number of Covid deaths into a tally of excess mortality due to Covid seems like it should be quite trivial, at least in a functional health system with widespread testing and reliable registration of vital events, including cause-of-death.[3] Yet Covid poses a couple of challenges to analysts wanting to use these types of data to identify Covid-related mortality. The first is a basic identification issue at the individual level. Even if someone infected with Covid dies, it is not clear whether Covid was the primary cause, an enabling "underlying" condition, or simply a background characteristic. In each of these cases, that person is added to the tally of Covid deaths, irrespective of whether, in the absence of Covid, s/he: (a) would likely have lived for many more years; or (b) was already at death's door. The first of these scenarios is a clear example of Covid-induced excess mortality. The second

1 See *Mortality Analyses* on the Johns Hopkins University website and the *COVID-19 Situation Dashboard* on the European Center for Disease Control site.

2 See Israel's *Covid-related data repository* and the *Ministry of Health dashboard*.

3 Things are much more complicated in developing countries. See work by Stéphane Helleringer and colleagues on Malawi.

is more ambiguous: Covid merely accelerated movement over the threshold.[4] In either case, this identification issue is one of the core problems in trying to estimate a clean Covid-induced probability of death. For perspective: an analysis of Covid-19 deaths in the US showed that in only 6% of cases was Covid-19 the only cause of death mentioned. In the remaining 94% of cases, an average of 2.6 other medical conditions were mentioned (CDC, 2020).

The second challenge to analysts wanting to convert the official number of Covid deaths into a tally of excess mortality is the distinction between the direct and indirect mortality effects of Covid. This is more of a system-wide issue. An earlier Taub Center publication discusses how the low levels of slack in Israel's acute care system in the pre-epidemic period, in addition to high rates of infection among medical staff during the epidemic, threatened to pull scarce medical resources away from treating and preventing other acute conditions. Our concern was that these factors would lead to a rise in deaths that would not be coded as Covid-induced (Weinreb & Chernichovsky, 2020). Subsequent reports in other developed countries provide some empirical support for this concern about the indirect mortality effect of Covid: sharp reductions in urgent cancer referrals and in the initiation of first-time cancer treatment in the UK (BMA, 2020); an increase in undetected cancer cases in Spain (Minder, 2020); and in the US, both a resurgence of drug-overdose deaths (Katz et al., 2020a), and an uptick in deaths attributed to diabetes, Alzheimer's, and high blood pressure (Lu, 2020).

To sidestep these two problems, the estimates of excess mortality in this paper are based on a simpler indirect method that focuses on the differences in all-cause mortality between 2020 and prior years. Comparisons of this type using Israeli data have been reported in the local media over the last couple of months, but have focused on comparative trends in the absolute number of deaths (Ashkenazi, 2020; CBS, 2020b; Karlinski, 2020; Less, 2020). That is, they compare the number of people who died in March–August, 2020 to the number in the same months in the last few years. The same approach has been employed in the US where, for example, teams of journalists and data scientists have used provisional death counts periodically released by the US

4 This is commonly referred to as the "comorbidity" or "multimorbidity" problem, and is not unique to Covid. It is a longstanding and widely known problem in using cause-of-death data, since deaths frequently occur to people who have multiple health problems. Ho and Hendi (2018), for example, note that influenza can trigger deaths from cardiovascular or chronic obstructive pulmonary diseases, which makes it difficult to directly estimate influenza's discrete mortality impact.

Centers for Diseases Control and Prevention (CDC).[5] The most recent such estimates in the US point to an 18% increase in the number of deaths between March 15 and November 7 relative to patterns in recent years (Katz et al., 2020b).

These comparisons make sense but have three problems, especially in Israel. The first two arise from the focus on the absolute number of deaths. That:

i. Ignores general levels of population growth, around 1.9% per year in Israel. Under those conditions, even if the mortality rate remained the same, the number of deaths would increase as a simple function of the greater number of people;

ii. Ignores age-specific patterns of population growth, in particular the much faster growth rate of the population aged 70+ — exceeding 4.0% per year in Israel in the 2017–2020 period. Again, this implies that the number of deaths would increase as a simple function of the greater number of people in these older age groups, where the probability of death is highest with or without Covid.

The solution to these first two problems is to look at trends in the underlying age-specific mortality rates, that is, the number of deaths occurring to people of a given age divided by the number of people of the same age. A version of this method was used by the Central Bureau of Statistics in their September 2020 assessment of excess mortality (CBS, 2020b). Yet herein lies the third problem:

iii. Age-specific mortality rates in Israel have been falling over time (shown below). This suggests that excess mortality should be measured in relation to the anticipated level of mortality in 2020 in the absence of coronavirus.

The CBS estimates do not use this approach. Instead, they compare 2020 mortality rates to those of 2015–2019 (the same 5-year range used to anchor the US estimates in Rossen et al., 2020). This implicitly assumes no reduction in age-specific mortality over the last 2.5 years. It would be like measuring the effects of Covid on macroeconomic growth by comparing actual GDP in 2020 to its level in 2019 rather than to its anticipated 2020 level.[6]

5 See *Excess Deaths Associated with COVID-19* on the CDC website.

6 The CDC estimates also do not account for anticipated changes in mortality rates in their analyses of US data (Rossen et al., 2020), but that is a more valid choice in the US context since life expectancy in the US has actually fallen since its peak of 78.9 in 2014. In 2018, it was 78.7, the same as level as in 2010 (Kochanek et al., 2020).

Data and methods

The estimates presented here fuse two main types of data.

1. Provisional data on daily number of deaths by age. These data are made available every month by the Central Bureau of Statistics. We use files covering all 365 days in 2000, 2001, 2005, 2006, 2010, 2011, 2015–2019, and 2020.[7]
2. Mid-year population (June 30) for each age group in the years specified in 1). The 2000–2019 data were released in the CBS Annual Statistical Abstracts.[8] Estimates for 2020 are not yet available so we use the Taub Center's population projections (Weinreb, 2020). The one weakness of these CBS mid-year population data is that they aggregate all older ages into a single "75+" category, which means that we cannot make finer distinctions between, say, the mortality of 70–79-year-olds and 80–89-year-olds.

Since Israel has a relatively small population and low mortality rates, especially at younger ages, these data were smoothed in order to reduce random fluctuations. First, in each of the years mentioned in 1), all daily deaths at each age *x* were summed into a weekly number of age-specific deaths, *d*, where subscript *t* indexes the particular week. This was further smoothed by generating a 3-week centered average around $d_{x,t}$, such that:

$$\bar{d}_{x,t} = (d_{x,t-1} + d_{x,t} + d_{x,t+1})/3$$

Note that specifying a centered mean censors the first and last weeks of the year, so the annual counts of deaths run for 50 weeks each year — from January 7 to December 24.

7 The CBS emphasizes that these death data are provisional. In a comparison of deaths in October and November across two successive files — released in December 2020 and January 2021 — we found virtually no change in deaths recorded before November, and only minimal changes after that. In a further test, we compared mortality rates for November across the two files. Numeric differences were minimal. Substantive differences were non-existent.

8 Using the midpoint estimate is standard practice in demography since, under normal circumstances, it captures the average population level in a calendar year, which in turn allows for the estimation of rates instead of probabilities. For more details, refer to Preston et al., 2000.

The weekly measure of age-specific mortality rate, m_x, is the conventional, $\bar{d}_x/N_x$ where N is the population aged x.

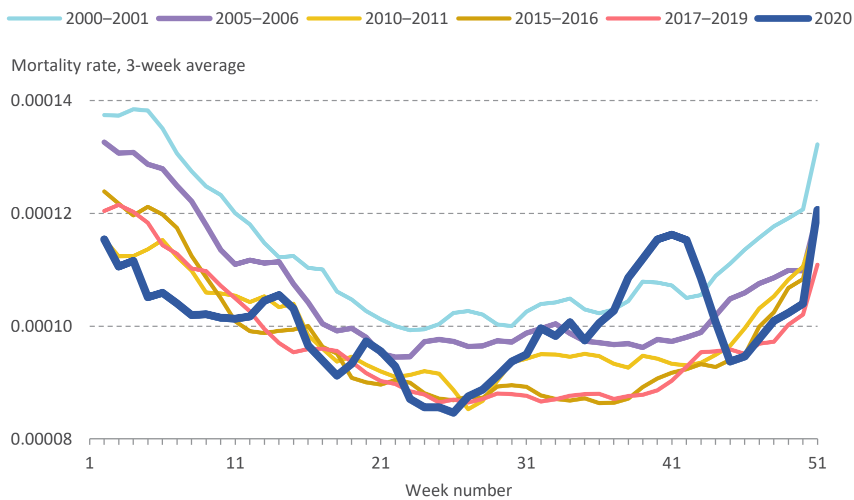
To generate a single mortality rate for the population in any given week, m_t, the age-specific mortality rate, $m_{x,t}$, was multiplied by the proportion of the total population, C_x, that is in age group x at the midpoint of that particular year y. Hence:

$$m_t = \sum_{x=0}^{\infty} m_{x,t} \cdot C_x$$

To smooth these functions, each weekly estimate of mortality was averaged across two years: 2000–2001, 2005–2006, 2010–2011, 2015–2016. These allow us to get a sense of how much the mortality rate in a given week has changed over consecutive five-year periods. Finally, to generate a smoothed measure of recent mortality, the weekly estimates were smoothed over the 2017–2019 period.

Figure 1 presents the first product of these procedures, with discrete mortality curves for each cluster of years and that of 2020 presented alone: the thick blue line. The standard shallow U-shape can be seen in all years, indicating seasonal fluctuations in which mortality peaks in January and bottoms-out in the June–August period. There are also notable reductions in mortality over the 2000–2010 period, slower reductions between 2010 and 2015–2016, and no notable improvement since then. This fits recent reports in Israel and other developed countries that point to a slowdown in the reduction of mortality, and even an increase in some years as the health consequences of rising obesity, diabetes and “deaths of despair” begin to outweigh the gains due to improved treatment of vascular diseases and cancer (OECD, 2019; Raleigh, 2019).

Figure 1. Mortality rate by week, selected years



Source: Alex Weinreb, Taub Center | Data: CBS

From the very start of 2020, mortality looks quite different. Over the first 11 weeks of 2020, Israel experienced the lowest mortality rates it had ever experienced in that season: fewer than 11 deaths per 100,000 residents per week after mid-January. That was a 7% reduction in the mortality rate relative to the first 11 weeks of 2017–2019.

The impact of the Covid epidemic on mortality can be seen from late March. The first official Covid death in Israel occurred on March 20 (week 12). That marks the beginning of the first wave of higher mortality before a sharp return to more normal patterns by early May (week 18). A slightly shorter second wave of higher mortality began at the end of May — interestingly, official Covid deaths were very low during that period so this was driven by other causes of death.[9] A much more significant rise in mortality began in early July and rose steadily through that month — this was the second wave of Covid mortality. From early August until late September, mortality levels in Israel were at

9 A lagged effect of acute non-Covid cases sidelined in April — the "indirect mortality" effect of Covid? A sudden spike of Spring flu? We will only know once cause-of-death data are released, which is typically more than a year after the event.

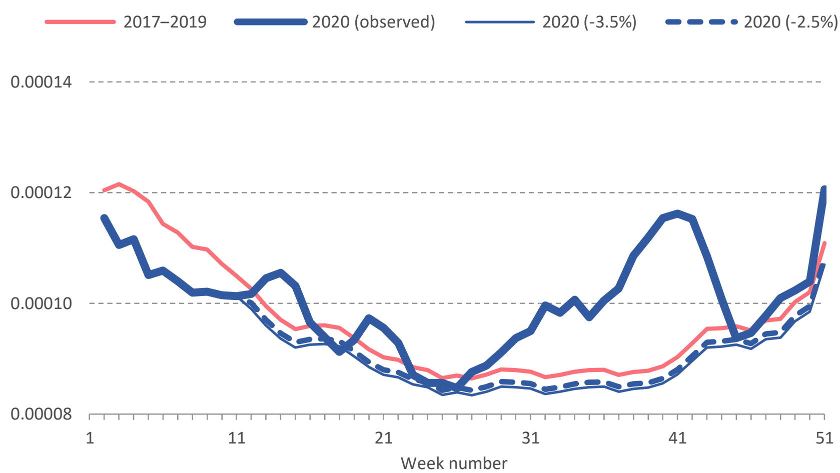
or above the 2005–2006 level. From then until the final week of October, mortality rose to levels last experienced in the 1990s.

Equally important, however, between each of the first two waves up to early July, mortality rates fell to levels below those of the 2017–2019 period. This is an extension of the historically low mortality that Israel experienced in January and February. The reduction after the third wave in the late Fall was more moderate. From mid-November to mid-December, mortality fell to roughly the same levels as in 2015–2019. For the last two weeks of the year, it rose to levels last seen in 2005–2011.

Excess mortality

We specify three discrete estimates of excess mortality. Each is defined as the difference between the observed weekly mortality rate in 2020 and one of three counterfactual mortality series, each of which is graphed in Figure 2, and each of which indexes a hypothetical series of mortality rates in 2020 in the absence of the Covid epidemic.

Figure 2. Mortality rate by week, selected years, including counterfactual series 1 to 3



Source: Alex Weinreb, Taub Center | Data: CBS

The first estimate compares the cumulative number of deaths implied by the observed weekly mortality rate in 2020 — the thick blue line, as in Figure 1 — to cumulative deaths implied by the weekly mortality rates in the 2017–2019 period. The only modification we make to the latter in this first counterfactual is to adjust for changes in population size, which means using age-specific population of 2020 instead of 2017–2019, as in:

As noted earlier, this estimate of excess mortality assumes, following CBS (2020b), that there would have been no change in age-specific mortality rates in Israel between 2017–2019 and 2020. Figure 1 suggests that this is a flawed assumption: the overall mortality rate over the first 11 weeks of 2020 was 7% lower than the equivalent period in 2017–2019. However, we retain this estimate since it provides a heuristically useful minimum threshold for excess mortality.

The second and third estimates of excess mortality are calculated relative to a 2.5 and 3.5% reduction in overall mortality from the 2017–2019 mean.[10] These mortality schedules are represented by the thin blue line and the broken blue line in Figure 2. Given the observed 7% reduction in mortality in weeks 1–11 these overall reductions point, respectively, to a 1.3 or 2.6% reduction in mortality in weeks 12–52. As noted above, between the peaks of the April, June and July waves, mortality rates fell to these levels, which reinforces our assertion that they are about right.[11]

Table 1 summarizes the cumulative excess mortality between March 18, the week during which the first death from Covid in Israel occurred, and December 31, under each of the three counterfactual mortality series absent Covid-19. Note that according to Ministry of Health data, 3,338 people had died from Covid by that date.

10 The counterfactual 3.5% reduction is simply an annualized version of the 7% reduction in mortality observed in weeks 1–11, 2020, relative to the same period in 2017–2019. The 2.5% is a more moderate version of that, and is in line with recent historical patterns of mortality reduction. For example, all-cause mortality rates fell by 2.7% per year in Western Europe between 2003–2007 (Helis et al., 2011).

11 Formally, the number of deaths are for these two counterfactual series are:

$$\hat{d}^{-1.3\%} = \sum_{x=Mar\ 18}^{Dec\ 31} (m_t^{2017-19} \cdot 0.975) \cdot N^{2020}$$

and

$$\hat{d}^{-2.6\%} = \sum_{x=Mar\ 18}^{Dec\ 31} (m_t^{2017-19} \cdot 0.965) \cdot N^{2020}$$

Table 1. Cumulative excess mortality from March 18 to December 31, 2020

	Observed 2020	No change in mortality since 2017–2019*	Reduction in mortality relative to same period in 2017–2019	
			-2.5%	-3.5%
Estimated number of deaths	37,336**	34,774	34,001	33,660
Excess deaths in 2020		2,562	3,335	3,676
Increase in deaths relative to the same period, 2017–2019 (%)		7.4	9.8	10.9

Notes: *Assumes 2017–2019 mortality rates and 2020 population and age structure; ** Of which, 3,338 were officially categorized as Covid deaths in separate Ministry of Health files.
Source: Alex Weinreb, Taub Center | Data: CBS

Table 1 confirms that there were a significantly higher number of deaths in the March–December, 2020, period than during the same period in prior years. Accounting for the growth in population alone — the approach in CBS (2020b) — there were 2,562 (7.4%) more deaths than during the same period in 2017–2019. Accounting for anticipated reductions in mortality rates that would have occurred in the absence of Covid raises estimates of excess mortality. Specifically, if mortality rates in the absence of Covid had been 2.5% lower than during the same 2017–2019 period, there would have been 3,335 excess deaths in the March–December 2020 period, which is about 9.8% higher than the expected number. It is also virtually identical to the official count of 3,338 deaths. And if mortality rates in the absence of Covid had been 3.5% lower than during the same 2017–2019 period, there would have been more than 3,676 excess deaths in the March–December 2020 period, which is about 10.9% higher than the expected number.

Age-specific effects

In which age groups is excess mortality most pronounced? At first glance, this seems like an odd question since it is widely known that the risk of mortality from Covid rises with age at an increasing rate. Our concern here is whether Covid has a proportionately greater effect on mortality at older ages where the risk of mortality is already higher, or are the proportionate effects relatively equal across ages, or even concentrated at a younger age? Estimates from the US suggest that excess mortality has actually been greatest in the 25–44 age group and, since May, higher at ages 65–84 than at ages 85+ (Rossen et al., 2020).

We evaluate the magnitude of change in mortality across ages by comparing age-specific mortality in 2020 to age-specific mortality in the pooled 2017–2019 populations (results relative to 2015–2016 were substantively very similar). To smooth fluctuations, especially important below old age, since deaths are relatively rare, estimates are based on 5-week centered means. In young adulthood, where deaths are even rarer, estimates combine age groups. Results are presented in Figure 3 in terms of the percentage change in mortality rates in 2020 relative to the earlier period, by week. Panel (a) focuses on ages 55 and up, and panel (b) on ages 0–29.[12]

There are a number of notable trends. First and foremost, there are very significant differences in the direction and magnitude of mortality change between the old and the young. In general, in the three age 55+ cohorts, there were historically low mortality rates in the first two months of the year, particularly pronounced for those age 65+. Mortality rose to its 2017–2019 levels by mid-March, then fluctuated around those levels until around late July (weeks 31–32) when they began their precipitous climb to unseasonable October highs. The only real exception to this pattern is the early mortality bump in the 65–74 age group. Somewhat surprisingly, the highest proportionate increase in mortality relative to 2017–2019 levels during the first wave — peaking around weeks 14–15 — occurred in this age group, with only hints of an increase at ages above 75, and no sign whatsoever of increases in mortality in the 55–64 age group.

Change in mortality at youngest ages have a completely different pattern. In the 0–19 age group, mortality levels were 23.6% lower in 2020 than in 2017–2019. Among 20–29-year-olds, mortality levels were 4.4% lower in 2020 than in 2017–2019. The biggest exception to this was the bump in mortality in late May observed in Figure 3 — though official Covid mortality was almost zero in this period.

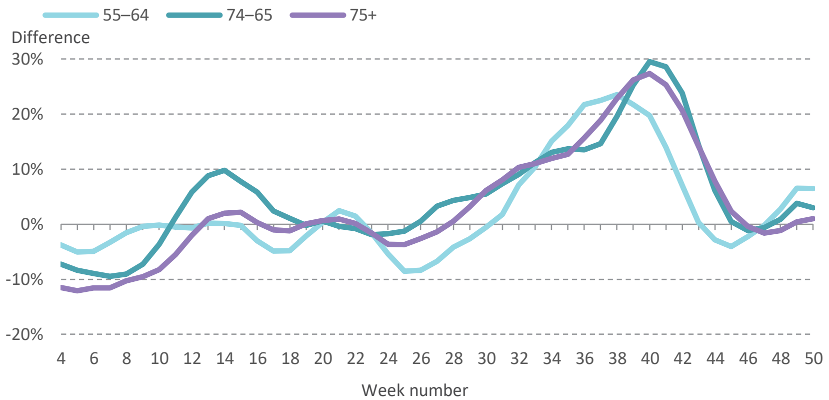
Together, these trends reinforce earlier assertions about the long-term downward trend in mortality in the population as a whole. Again, this is quite different to the US patterns documented by Rossen et al. (2020), in which mortality rates in both the 25–44 and 65–74 age groups were around 10% higher than the 2015–2019 levels for the first two months of 2020. More intriguing, the negative association between the timing of excess mortality in

12 Age-specific effects in the intermediate 30–54 age group have no clear pattern. Overall, though across all 12 months, they were 3.7% higher than in 2017–2019 for those aged 30–34, 2.4% lower for those aged 35–39, and a mere 0.4% higher for those aged 40–54.

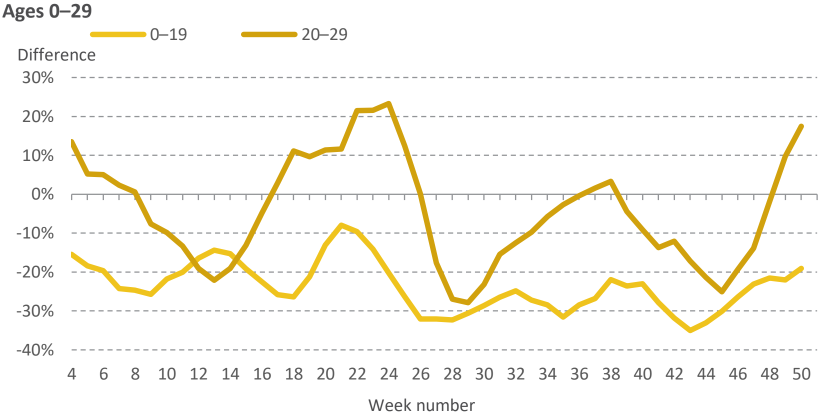
older age groups and those in the 20–29 age groups raises questions about possible behavioral responses to mortality events, especially if the reductions are also visible outside formal Covid lockdowns.[13]

Figure 3. Weekly mortality in 2020 relative to 2017–2019, by age group

a. Ages 55+



b. Ages 0–29



Source: Alex Weinreb, Taub Center | Data: CBS

13 Deaths among young adults are more frequently the results of injuries, accidents, and violence, than is the case for any other age group. Once cause-of-death data are available, we will be able to identify the specific sources of these changes.

Effects of age structure

The increases in mortality documented thus far are significant, but they would have been worse if Israel's age structure were more similar to that of other OECD countries. To understand this better, it helps to describe the rate more formally.

The overall number of deaths from Covid in each age group is a product of three things: the age-specific rate of infection; the age-specific probability of death from Covid; and the number of people in each age group.[14]

In light of the substantial differences in risk of mortality at different ages, it is clear that cross-country differences in the mortality impact of Covid are almost solely a function of how low a society can keep *i* (the percent infected), especially at older ages, and most especially in countries where a large proportion of the population is elderly. We show this through an "age standardization" exercise.

The three panels in Figure 4 presents the ratio of the age-specific proportion of new Covid infections to the proportion of the population in each age group, by month. This is the simplest way to see where the age pattern of infection deviates from the age structure of the population as a whole. In each of the panels, any column above "1" shows that infections are disproportionately concentrated in that age group; any value below "1" shows that there are disproportionately fewer infections in that age group.

Throughout, confirmed infections in Israel have been disproportionately concentrated among people in the 20–55 age groups, with particular high overrepresentation of people in their 20s. From July until the end of the year, there was also a disproportionately low number of infections among the elderly. During the first wave, the share of confirmed infections among people aged 80+ was more than 40% higher than that age-group's share of the population. By September, infections in that age-group had fallen to about 60% of its share of the population, though it rose again to almost parity in October before falling again in the final two months of the year. A similar trend can be seen in the other higher risk age groups, that is, all ages above 60.

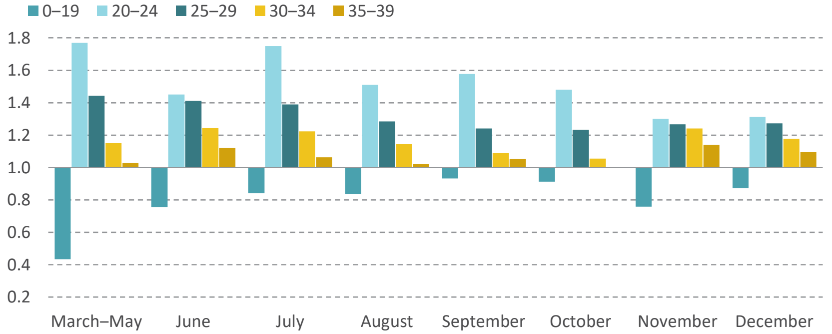
14 We sum these age-specific estimates into a single term, d_t^{Covid} :

$$d_t^{Covid} = \sum_{x=0}^{\infty} q_{x,t}^{Covid} \cdot i_x \cdot N_x$$

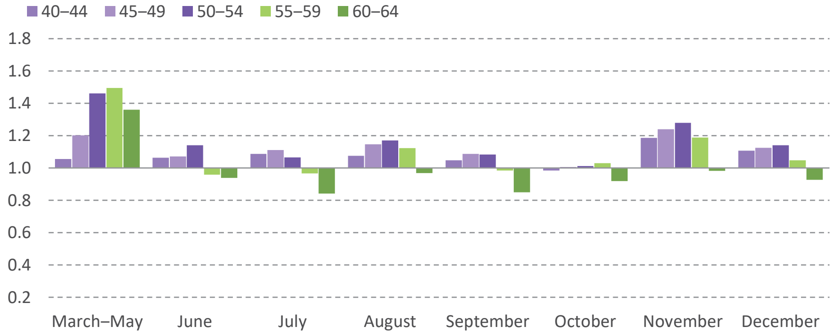
where *qCovid* is the probability of dying from Covid (imperfectly indexed here by case fatality ratios), *i* indexes the percent infected, and all other terms are as defined above.

Figure 4. The share of confirmed Covid infections by age relative to the share of the population in that age group, by month

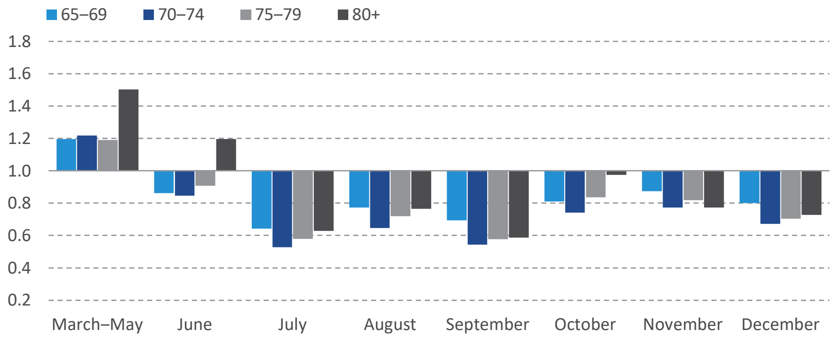
a. Ages 0–39



b. Ages 40–64



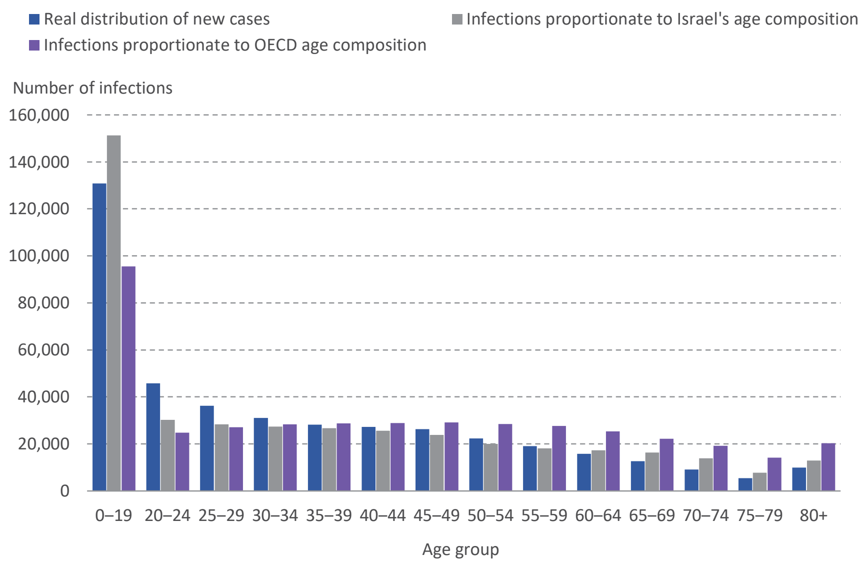
c. Ages 65+



Source: Alex Weinreb, Taub Center | Data: Covid-19 database; Weinreb, 2020; OECD database

These trends point to some success in shielding the elderly from infection in Israel. But they also raise the question of how much Israel's excess mortality would have increased if infection rates were proportionate to its age structure, especially for those at greatest risk of death. Or, by extension, how much would Israel's excess mortality have increased if it had the same age structure as an average OECD country, and infection rates were proportionate to that average OECD age structure. This second question is substantively equivalent to asking how many deaths Israel would have experienced if the age pattern of infection during Israel's second wave disproportionately affected the elderly, as it did during Israel's own first wave.

Figure 5. Number of infections by age, across age distribution scenarios



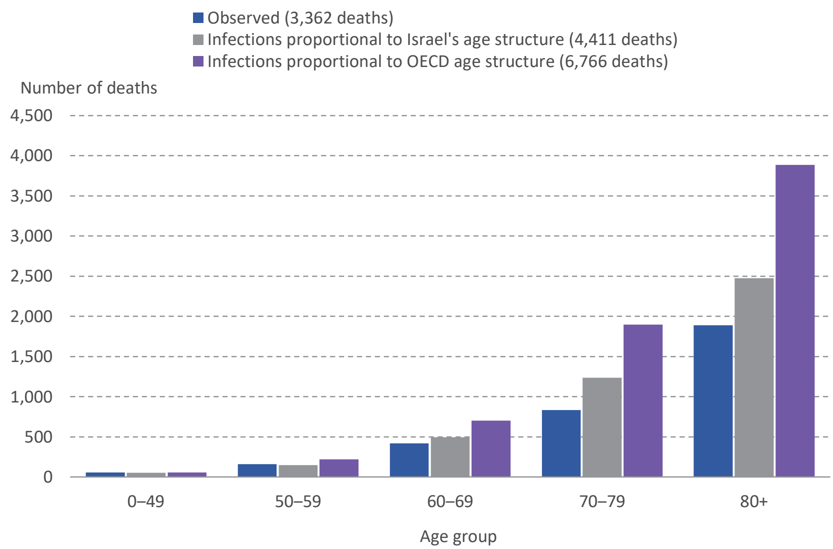
Source: Alex Weinreb, Taub Center | Data: Covid-19 database

The effects of these two hypothetical situations on the number of infections from age 20 and up are graphed in Figure 5, alongside the actual age-specific number of infections. The relative heights of the blue and orange columns show how much Israel's age-specific pattern of infection differs from its age structure — there would have been more than 10,000 more infections above age 70 if patterns of infection had been equivalent to the age structure. But this, in turn, is dwarfed by the difference between the blue and grey columns.

If the age-specific patterns of infection in Israel was consistent with the age structure of the OECD, the number of Covid cases above aged 70 would have more than doubled.

Figure 6 shows how these different age patterns of Covid infection would have affected mortality. It presents the number of deaths that actually occurred in the period under study (blue columns), and the number that would have occurred under two additional scenarios: if the age-specific infection rate in the March to December period was proportionate to Israel's age distribution (grey columns); and if the age-specific infection rate in the March to December period was proportionate to the mean age distribution across all OECD countries (purple columns).

Figure 6: Effects of shifting age-specific infection rates on total number of Covid deaths in Israel, March 18–December 31



Source: Alex Weinreb, Taub Center | Data: Covid-19 database

Here we see the very substantial effects of age structure on Israel's Covid mortality. If age-specific rates of Covid infection were in proportion to Israel's age structure, Israel would have experienced 1,048 additional deaths by December 31. That represents a 31% increase, with about 95% of that occurring above age 70.

But if age-specific rates of Covid infection were in proportion to the mean OECD age structure — which in Israel's case would mean disproportionately affecting the elderly, as it did during Israel's own first wave — Israel would have experienced 3,403 additional deaths by December 31. That would have more than doubled Covid mortality, with about 90% of that increase occurring above age 70.

Arguably, these are actually conservative assumptions. That is, if they are biased, they tend toward underestimating mortality. The reason: they do not take into account the extra burden on the medical system. On October 4, for example, Israel experienced the peak number of Covid cases clinically defined as "serious" in 2020: around 890 — it climbed above this in the second week of January, 2021. Even with extra medical infrastructure made available through the military, it is difficult to see how the Israeli medical system would have been able to maintain its relatively low case-fatality ratio for Covid, let alone sustain standards of care for other conditions, if it was confronting double that number of serious cases.

In either case, taking one of these alternative infection trajectories — recall that we are holding mortality rates constant — would also have affected Israel's place in international mortality rankings. As of December 31, instead of having around 38 deaths per 100,000, the 14th lowest in the OECD, it would have experienced around 50 deaths per 100,000 under the first scenario (infections proportional to Israel's own age structure) and 76 deaths per 100,000 under the second scenario (infections proportional to the OECD age structure). These would have placed Israel in 19th and 24th place, respectively, in terms of Covid mortality. In the latter case, in particular, Israel's mortality would have been higher than that of the Netherlands (66.3 per 100,000) and close to that of Sweden (86 per 100,000). It is clear, in other words, that much of Israel's advantage in terms of minimizing excess deaths from Covid — notwithstanding its very high infection rates — has stemmed from the relatively young age pattern of infection, in addition to a young age structure. This is at least a partial public health success.

Effects on life expectancy

A final perspective on the magnitude of Israel's excess mortality in 2020 is to evaluate its impact on measures of life expectancy. This gives a more comprehensive picture of a total mortality effect since life expectancy calculations build on a full age-range of mortality rates for a given time period.

To do this, we took the most recent set of male and female Life Tables published by the Central Bureau of Statistics (CBS, 2020a). We modified the series of age-specific mortality rates (m_x) implied by those tables by the percentage change in m_x between 2017–2019 and 2020. We then applied that modified mx schedule to the remaining weeks of the year, calculated the full life table, ending with estimates of life expectancy.[15]

Results of these estimations are presented in Table 2, with discrete estimates of life expectancy at birth, age 25 and age 65. We point to two main findings.

First, life expectancy at birth is expected to fall by 2.2 months for both men and women. This means that over the whole 2020 period, at least in terms of life expectancy, excess mortality associated with Covid, whether directly or indirectly, has outweighed the sharp reductions in mortality at younger ages shown in Figure 3.

Given the high infection rates, this decline is lower than expected. One microsimulation study suggests that each percentage increase in the prevalence of Covid-19 infection in Western Europe, North America or Latin America/Caribbean would reduce life expectancy by about 0.1 years, with a lower-bound estimate of 0.07 years (Marois et al., 2020). If Israel followed those patterns, its 423,200 confirmed cases by the end of 2020 — roughly 4.5% of the population — would lead to a loss in life expectancy of around 5.4 months (lower bound 3.8 months).

15 The CBS Life Tables provide l_x in single years of age. Following standard demographic procedures, we assumed an a_x distribution, then calculated d_x, L_x, m_x, T_x, then e_x using both the original CBS m_x schedule and the new Covid-19 m_x.

Table 2. Estimated life expectancy in life table, with 2020 changes to mortality rates, by sex and age

	Life expectancy Life Table m_x	Life expectancy Observed m_x 2020	Reduction in life expectancy (months)
At birth (e_0)			
Male	80.63	80.45	2.17
Female	84.35	84.17	2.17
At age 25 (e_{25})			
Male	56.06	55.82	2.91
Female	59.59	59.37	2.67
At age 65 (e_{65})			
Male	19.26	19.02	2.94
Female	21.56	21.38	2.62

Source: Alex Weinreb, Taub Center | Data: CBS

A second point to be seen in Table 2 emerges from the comparison of life expectancy at birth to life expectancy at ages 25 or 65. This tells us more about where in the age distribution the balance between loss to Covid mortality and gains to other types of mortality (e.g., at younger ages) are pushing life expectancy one way or the other. The main point here is that the loss in life expectancy increases from 0 to 25, but not from 25 to 65. These patterns are consistent with the reduction in mortality below age 30 (shown in panel b of Figure 3) and the generally similar proportionate increases in mortality at older ages (panel a of Figure 3).

Finally, even though a loss of 2.9 months for men and 2.6 months for women at age 65 is not trivial — in relation to the 19–21 years of life expectancy at that age — it is much less than the anticipated reduction based on the microsimulation study. And it is also much less than the likely reduction in life expectancy in other countries that have much higher Covid mortality than Israel. This cannot only be due to age structure effects since the age structure of many countries in Latin America and the Caribbean is much more similar to that of Israel than to European countries. Rather, it implies that CFRs in Israel are also lower than expected in the Marois et al. model. This is consistent with the rates we show in the Appendix.

Conclusions

The Covid-19 pandemic has generated a significant amount of excess mortality in Israel. As of the end of December, the official count was 3,338 deaths from Covid. That implies that there was about a 2.5% reduction in all other causes of mortality (in the absence of Covid) relative to 2017–2019 levels.

We identify the first signs of this excess mortality among 65–74-year-olds in April. It can then be seen across all groups above age 55 beginning in late July, with a steady increase to 30% excess weekly mortality in early October. This was the height of Covid's second wave in Israel, during which the overall mortality rate reached levels not seen during the same late Summer/early Fall season since the 1990s, when Israel's life expectancy was at least 4 years lower than it is today. Overall, accounting for the growth in population, this Covid-era mortality surge has increased the number of deaths by roughly 7.4% over the same March–December period in 2017–2019. Taking into account anticipated reductions in mortality in the absence of Covid, that represents a 9.8–10.9% in the number of deaths relative to the same March–December period in 2017–2019.

These increases are significant, but they are much less than similar estimates conducted elsewhere. In the US, for example, accounting for changes in population size but not anticipated changes in life expectancy, there was an 18% increase in number of deaths up to early November (Katz et al., 2020b).

Other data shown here demonstrates that Israel's excess mortality could easily have been higher. Outside the periods of excess deaths, mortality rates were lower in most age groups than they had been in the 2017–2019 period. This was especially the case among 0–19-year-olds, whose mortality rates were 23% lower than 2017–2019 levels across the whole year. It was also the case amongst those aged 65 or above, where mortality rates were about 10% lower for about the first 10 weeks of the year. Were it not for these lower mortality trends, the overall number of excess deaths across year would have been even higher. Likewise, excess mortality would also have been much higher if Israel's age pattern of infection more closely reflected its age structure or, more especially, if it more closely reflected the OECD age structure.

The excess mortality across 2020 as a whole will lead to a 2.2-month drop in life expectancy at birth, and a 2.6–2.9-month drop in life expectancy at age 65. That reversal in life expectancy is a relatively unusual occurrence in Israel, but it is increasingly common in developed countries in general.

Since 2011, year-on-year gains in life expectancy in the US and most EU countries have been much more sluggish than they were in the prior decade, as progress in addressing cardiovascular diseases has slowed, and as deaths arising from obesity, diabetes, drugs and suicide (the last more specific to the US) have become more common (Raleigh, 2019). In that situation of relative stability, it is easier for an epidemic to lead to a temporary reduction in life expectancy. This was the case in 2015, when a major influenza epidemic reduced life expectancy in most European countries, including by more than three months in Germany and Italy, both of which have excellent healthcare systems (Ho & Hendi, 2018). Another major influenza epidemic occurred in 2009 (Dawood et al., 2012). In the context of those recent reductions, Israel's loss of 2.2 months of 2020 life expectancy to Covid is actually quite moderate. That said, it remains an open question how much Covid mortality will bleed into 2021. Writing in February 2021, we note much higher Covid mortality over the last month than at any time during 2020, even with the very rapid vaccination campaign against Covid. In addition, the longer the medical system as a whole is focused on Covid, the more likely we are to see an indirect mortality effect associated with conditions that were undiagnosed or undertreated during the epidemic.

Yet there is also an alternative, more optimistic scenario. Mortality could bounce back to its prior downward trajectory, whether because of a classic selection effect — the population is, on average, healthier than it was immediately prior to the epidemic — or because of new investments in the health system, or changes in health behavior. One positive effect is certainly likely: even moderate mask-wearing and social distancing will reduce the incidence of other communicable diseases, in particular respiratory diseases. There have, for example, been almost no influenza deaths during the 2020–2021 winter season.

It is worth recalling that the estimates provided here are based on what the CBS itself calls "provisional" data on deaths, so deaths over the final few weeks of December may change a little. More importantly, our estimates only describe trends at the national level. They do not allow us to identify subpopulations that have been more or less affected. Other data released by the government show that by mid-October, at least 13% of the population of major Haredi cities — Bnei Brak, Modi'in Illit — had experienced Covid, with half of all infections among people aged 65+ in mid-October being Haredim (Nachshoni, 2020).

Coupled with reports of higher Covid-related mortality in this population — four times as high as their proportion in the population among people aged 65+ (Frosh, 2020) — these elevated rates of infections point to significant Covid-related mortality in this population, suggesting that Israel's excess mortality has been disproportionately located in Haredi areas, and that any impact on life expectancy will also be more concentrated there. Again, this parallels group-level differences in the US. In a recent paper in PNAS, Andrasfay and Goldman (2021) estimate that although Covid has reduced life expectancy in the US by 1.2 years as a whole, it has reduced life expectancy among Blacks and Latinos by about 3 to 4 years. Note that these estimates are specific to 2020. They do not include the longer-term indirect effects on life expectancy associated with Covid-related unemployment and poverty (Bianchi et al., 2020).

Excess mortality may also be somewhat higher in Israel's Arab population. Here the cause is not significantly higher rates of infection but comorbidities, especially diabetes, whose prevalence is three times as high as in the Jewish population, and that significantly raises the risk of mortality from Covid.

For now, however, we return to our principal finding. After beginning the year with two months of lower-than-expected mortality, Israel has experienced considerable excess mortality, roughly 10% more than it should have experienced. We await more detailed city- or population-specific data to evaluate how much these trends vary across different subpopulations, and cause-of-death data to check on specific pathways.

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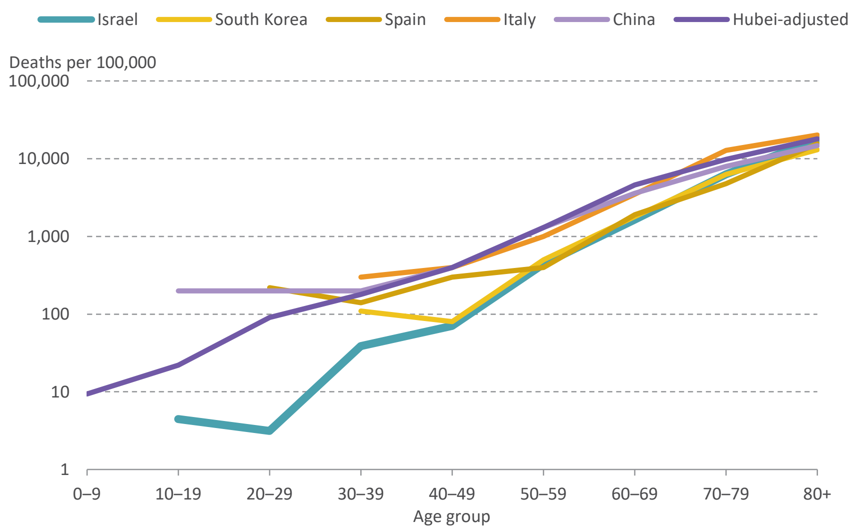
Appendix

Israel's Case Fatality Ratio (CFR) in international perspective

Israel's age-specific CFR from Covid during 2020 was relatively low by international standards. Up to the 70–79 age group it was almost identical to that of South Korea — from 80+ it leaped above South Korea's. Israel's CFR was also marginally lower than that of Spain, and significantly lower than the CFR reported in China in early 2020 (Riou et al., 2020), New York between March and June 2020 (Yang et al., 2020) and Italy up to August 18 (Signorelli & Odone, 2020).

Appendix Figure 1. Mortality rate among those infected with Covid in selected countries, by age



Source: Alex Weinreb, Taub Center | Data: Covid-19 database; Rious et al., 2020; Signorelli & Odone, 2020; Yang et al., 2020.

Appendix Table 1 shows the coefficient of variation (CV) for CFR at every age across these six estimates. It confirms that these differences in CFR between countries are more pronounced at younger than older ages. This makes sense for two reasons. First, there are substantial differences in percent tested across countries, especially at younger ages when more people tend to have minor symptoms, allowing them to avoid testing. Second, differences in likelihood of death at older ages are likely to be minimal across developed countries as treatment protocols and clinical skills continue to develop and are shared across transnational medical and scientific networks. Any residual difference mortality is more likely to be the result of the prevalence of comorbidities and saturation of health infrastructure.

Appendix Table 1. Case Fatality Ratio from Covid-19 in selected countries, by age

Age	Coefficient of variation
30–39	0.5485
40–49	0.5801
50–59	0.5203
60–69	0.4312
70–79	0.3626
80+	0.1561

Source: Alex Weinreb, Taub Center

This reduction in CV with age is important because it suggests that the CFR is a better proxy for covid-related mortality at older ages — where the impact of mortality is much higher — than at younger ages.