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Vaccinating Australia: How long will it take?

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ABSTRACT

The Australian Government began to roll out the national COVID-19 vaccination program in late February 2021, with the initial aim to vaccinate the Australian adult population by the end of October 2021. The task of vaccinating some 20 million people presents considerable logistic challenges, but a rapid rollout is essential to allow for the reopening of borders and is especially urgent as new more transmissible variants arise. Here, we run a series of projections to estimate how long it will take to vaccinate the Australian population under different assumptions about the rate of vaccine administration, the schedule for vaccine eligibility and prevalence of vaccine hesitancy. Our analysis highlights the number of vaccine doses that can be administered per day as the key factor determining the duration of the vaccine rollout. A rate of 200,000 doses per day would achieve 90% population coverage by the end of 2021; 80,000 doses a day would see the rollout extended until mid-2023. Vaccine hesitancy has the potential to greatly slow down the rollout and becomes the main limiting factor when the supply of vaccine doses is high. Speed is of the essence when it comes vaccinating populations against COVID-19: a rapid rollout will minimise the risk of sporadic and costly lockdowns and the potential for small, local clusters getting out of control and sparking new epidemic waves. In order to achieve rapid population coverage, the Australian government must ramp up vaccine administration to at least 200,000 doses per day as quickly as possible, while also promoting vaccine willingness in the community through clear public health messaging, especially to known hesitant demographics.

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1. Introduction

The development and regulatory approval of multiple safe and efficacious COVID-19 vaccines in less than a year is a truly remarkable achievement. The logistical task of administering the vaccine rapidly and equitably to billions of people around the world will be no less of a challenge. In the final weeks of 2020, national vaccination programs began to roll out in several countries including Israel, the United States and the United Kingdom. In Australia, the federal government has entered into five agreements for the supply of COVID-19 vaccines (Table 1) and started administering the Pfizer/BioNTech vaccine to the highest priority group in late February 2021. The Australian government initially set an ambitious target to vaccinate the adult population by October 2021, [1] leaving just 35 weeks to administer two doses each to some 20 million adult Australians. This target was subsequently abandoned.

The national roll-out strategy divides the population into 16 groups, organised into five distinct phases (Table 2). The rollout began through hospital hubs with access to −70C ultra-cold-chain storage facilities administering the Pfizer/BioNTech vaccine to the highest priority groups scheduled in Phase 1a, which includes border workers and frontline healthcare staff [2]. Private contractors were engaged to vaccinate aged care staff and residents. Having received approval from the Therapeutic Goods Administration (TGA) in February, the AstraZeneca vaccine was initially scheduled to be administered to the bulk of the adult population through a network of general practitioners (GPs) and community pharmacies. Emerging evidence of thrombosis with thrombocytopenia syndrome as a rare but potentially fatal side effect of the AstraZeneca vaccine, [3,4] led The Australian Technical Advisory Group on Immunisation (ATAGI) to recommend the Pfizer vaccine for adults aged under fifty and the AstraZeneca vaccine only for people 50 and over on April 7 [5]. From mid-April, the hospital hub and GP-centered rollout was supplemented with cen-

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Table 1
Vaccine supply agreements entered into by the Australian Government[†]

Name	Type	Doses (millions)	Schedule	Status as at 01 June 2021
Pfizer/BioNTech	mRNA vaccine	40	2 doses, 21 days apart	Provisionally approved by the Therapeutic Goods Administration for individuals 16 years and older.
University of Oxford AstraZeneca	Viral vector vaccine	53.8	2 doses, 84 days apart	Provisionally approved by the Therapeutic Goods Administration for individuals 18 years and older. The Pfizer vaccine is recommended for individuals aged 50 years and over but the AstraZeneca vaccine can still be given to adults under 50 years if the benefit of vaccination is likely to outweigh risk, and where informed consent has been obtained.
Moderna	mRNA-based vaccine	25	2 doses, 28 days apart	Phase 3 clinical trials; An application by Moderna to the TGA is anticipated.
Novavax	Protein vaccine	51	2 doses, 21 days apart	Undergoing TGA evaluation.
COVAX Facility	Assorted	25	Assorted	Nine candidate vaccines in various clinical trial stages.

[†]Adapted from https://www.health.gov.au/node/18777/australias-vaccine-agreements.

Table 2
Australia's COVID-19 vaccination national roll-out strategy[†].

Phase	Description	Size
1a	Quarantine & border workers	70,000
1a	Frontline health care workers	100,000
1a	Aged care and disability care staff	318,000
1a	Aged care and disability care residents	190,000
1b	Elderly adults aged 80 years and over	1,045,000
1b	Elderly adults aged 70–79 years	1,858,000
1b	Other health care workers	953,000
1b	Aboriginal and Torres Strait Islander people aged 55 years and over	87,000
1b	Younger adults with an underlying medical condition	2,000,000
1b	Critical and high-risk workers	196,000
2a	Adults aged 60–69	2,650,000
2a	Adults aged 50–59	3,080,000
2a	Aboriginal and Torres Strait Islander people aged 18–54	387,000
2a	Other critical and high-risk workers	453,000
2b	Balance of adult population	6,643,000
3	<18 if recommended	5,670,000

[†] Adapted from https://www.health.gov.au/sites/default/files/documents/2021/01/covid-19-vaccination-australia-s-covid-19-vaccine-national-roll-out-strategy.pdf.

tralised mass vaccination centres including the Melbourne Exhibition Centre and Sydney Olympic Park.

The Pfizer/BioNTech and AstraZeneca vaccines both require two doses—a primer and a booster—which need to be delivered within a specified time frame after the initial shot. Current TGA guidelines state that the second Pfizer/BioNTech dose should be administered three weeks after the first dose, while the second AstraZeneca dose should be delivered twelve weeks after the first dose for optimal efficacy, although a minimal interval of four weeks can be used in extenuating circumstance. This scheduling complicates roll-out as the resources of specialised vaccine administration facilities and nominated general practices and pharmacies must be divided between unprotected individuals waiting for their first injection and those who have already been afforded some protection and who are returning for their booster administration. Furthermore, the duration of protection afforded by these vaccines is not yet well characterised, and re-vaccination of some or all of the population may be required. We have not included re-vaccination into the any of the scenarios examined in this paper, at this stage.

Another unknown is the question of vaccine hesitancy, which refers to delay in acceptance or complete refusal of vaccination, despite a suitable vaccine being available and accessible [6]. Clearly, high levels of vaccine hesitancy would have the potential to undermine efforts to establish adequate protection of the whole population through herd immunity. An online survey of over 3,000 Australian adults undertaken in August 2020 asked respondents if they would agree to vaccination for COVID-19 if a safe and effective vaccine were available. The population-weighted responses were 5.5% *definitely not*, 7.2% *probably not*, 28.7% *probably will* and 58.5% *definitely will* [7]. When the same individuals were followed up in January 2021, a slight trend towards vaccine hesitancy was evident, with 7.8% responding *definitely not* and 13.2% *probably not* to the same question. A subsequent follow-up with the same group of respondents in April 2021 did not find any further trend towards vaccine hesitancy, [8] despite the considerable amount of negative publicity on the rare but potentially fatal side effects linked to the AstraZeneca vaccine in the intervening months. Although vaccine willingness remains reasonably high, 82% of respondents did express some concern about potential vaccine side effects, and this appeared to be driven by concerns of adverse side effects, particularly related to the AstraZeneca vaccine [8].

When it comes to vaccine roll-out, speed is of the essence. Statistical modelling has illustrated that epidemic duration, need for non-pharmaceutical interventions, cases and deaths are minimised dramatically as the number of available daily vaccinations increases [9,10] In one modelling scenario, for example, increasing the daily capacity by 25% from 75,000 to 100,000 resulted in a 60% reduction in total cases and deaths [9].

A timely vaccine rollout is also essential to support a safe return to pre-pandemic levels of international arrivals into Australia. While to date public health authorities have largely managed to contain the sporadic leaks from Australia's hotel quarantine system through case isolation, contact tracing and limited local lockdowns, this success has been in the context of a relatively low numbers of arrivals. The economic and societal imperatives to ease the international border restrictions and allow larger numbers of overseas arrivals will increase the attendant risk of importing new cases and potentially more virulent variants. The emergence of variants of concern with vaccine resistance and high transmissibility further increases the urgency for mass vaccination. High vaccine coverage can help mitigate the risk of any ensuing outbreaks, provided vaccines are rolled out rapidly [9].

The aim of this analysis is to estimate how long it might take to administer the two-dose COVID-19 vaccine schedule to the Australian population. We consider a variety of scenarios based on daily vaccine administration capacities, the scheduled opening for each vaccine priority phase and the degree of vaccine hesitancy in the population. We conclude by comparing Australia's daily vaccine administration rates per capita with countries where vaccination programs are already under way.

2. Methods

2.1. Population and priority groups

Our analysis population is based on the 16 priority groups and five phases proposed by the Australian government (see Table 2). The assumed population size is 25.7 million people, including 5.67 million children and adolescents under the age of 18. We assume that equal priority will be given to all groups within the same phase.

2.2. Vaccine roll out projections

Roll out projections are based on three parameters:

1. The daily vaccination capacity.
2. The schedule for opening the remaining vaccine phases.
3. Vaccine hesitancy.

2.3. Projection scenarios

Projection scenarios are based on a 2^k factorial design defined by three factors with two levels each. The scenarios are summarised in Table 3 and the three factors and levels are detailed below:

- Daily vaccination capacity (80,000 versus 200,000)
- Opening schedule for the remaining phases (earlier opening versus later opening)
- Vaccine hesitancy (less hesitant versus more hesitant).

All scenarios assumed a run-in period of 100 days to build up the specified daily vaccination capacity.

2.4. Schedule for opening phases

Phase 1A, 1B and 2A were opened on 22 February, 22 March and 4 May 2021 respectively. National opening dates for Phase 2B and Phase 3 have not been announced as of June 2021, although there is increasing variability across the states and territories as the roll-out progresses. For example, all individuals aged 16 and older were eligible to receive the vaccine in regional South Australia and the Northern Territory from 25 May and 8 June respectively. We specified two scenarios for the scheduled opening of Phases 2B and 3: the earlier opening scenario opening both phases on 5 July; the later opening scenario opens Phase 2B on 2 August and Phase 3 on 1 November.

2.5. Vaccine hesitancy

The projections assume that attitudes towards receiving the vaccine can be classified as one of four categories: *definitely will*, *probably will*, *probably won't* and *definitely won't*. We explored two scenarios that varied the distribution of these categories within the five vaccine phases (Table 4). In the less hesitant scenario, the proportion defined as *definitely won't* had a maximum value of 5%. In the more hesitant scenario, this value was increased to 8% for Phases 1B, 2B and 3, and 10% for Phase 2A (the majority of whom are scheduled to receive AstraZeneca). In both scenarios, vaccine hesitancy was assumed to be negligible among the highest priority and most vulnerable groups in Phase 1A.

Table 3
Overview of projection scenarios.

Scenario	Capacity (doses per day)	Opening schedule	Hesitancy
1	80,000	Earlier opening	Less hesitant
2	80,000	Earlier opening	More hesitant
3	80,000	Later opening	Less hesitant
4	80,000	Later opening	More hesitant
5	200,000	Earlier opening	Less hesitant
6	200,000	Earlier opening	More hesitant
7	200,000	Later opening	Less hesitant
8	200,000	Later opening	More hesitant

2.6. Vaccine allocation

We allocated the daily available vaccination doses according to the following algorithm:

1. Calculate the number of second doses due on a given day, based on the scheduled timing for second doses (21 days after the first dose for individuals receiving the Pfizer vaccine and 84 days after the first dose for individuals receiving the AstraZeneca vaccine). If the number of second doses due exceeds the daily limit, assign as many doses as required and do not assign any first doses.
2. Assign the remaining doses from the daily limit to those awaiting their first dose.
3. Identify all phases that are eligible to be vaccinated, based on the phase opening dates.
4. Draw a random sample of "willing" vaccinees from the eligible phases for that day, with the probability of being willing specified as a function of vaccine attitude, as described in Supplementary Table S1.
5. Divide the available first doses between individuals who are both eligible and willing, in proportion to the total number of eligible and willing individuals in each phase.

2.7. Software and code

The analysis was performed using R version 4.0.3 [11] and associated packages [12]. The complete source code to reproduce this analysis can be accessed at https://github.com/CBDRH/vaccinatingAustralia.

3. Results

Results from the eight scenarios are presented in Table 5. Starting from 22 February 2021, the projected time to vaccinate 90% of the adult Australian population ranged from December 2021 (Scenario 7) to May 2023 (Scenario 4) across the eight scenarios compared.

Under an optimistic scenario of 200,000 daily doses with relatively low hesitancy and early opening of all phases (Scenario 5) Australia would reach 90% population coverage in January 2022. Under the four less optimistic scenarios of 80,000 doses administered daily, it would take until between December 2022 and May 2023 to achieve 90% population coverage of the adult population (Table 4). Under Scenario 1, we would reach 50% population coverage (25.7 million administered doses) around the start of March 2022 and 75% population coverage (40 million administered doses) in August 2022 (Fig. 1A).

Comparing the projections that differed only in terms of hesitancy, scenarios with relatively high hesitancy took an additional three to four months for all phases to reach 90% coverage (e.g. December 2022 in Scenario 3 versus May 2023 in Scenario 4, Table 5 and Supplementary Figure S1). The adverse impact of higher vaccine hesitancy was more acute in scenarios where the number of daily doses available was higher. For example, the higher vaccine hesitancy resulted in a delay of four months for

Table 4
Profile of vaccine hesitancy for the less hesitant and more hesitant vaccine scenarios.

		Attitude towards receiving the vaccine			
Scenario	**Phase**	**Definitely will (%)**	**Probably will (%)**	**Probably won't (%)**	**Definitely won't (%)**
Less hesitant	1a	90	10	0	0
	1b	60	28	7	5
	2a	60	28	7	5
	2b	60	28	7	5
	3	60	28	7	5
More hesitant	1a	90	10	0	0
	1b	43	36	13	8
	2a	30	40	20	10
	2b	43	36	13	8
	3	43	36	13	8

Table 5
Summary of vaccine rollout projections for different scenarios.

	Projected date to reach 90% coverage				
Scenario	**Phase 1a**	**Phase 1b**	**Phase 2a**	**Phase 2b**	**Phase 3**
Scenario 1	May 2022	Nov 2022	Jan 2023	Nov 2022	Nov 2022
Scenario 2	Feb 2022	Feb 2023	May 2023	Mar 2023	Mar 2023
Scenario 3	Apr 2022	Nov 2022	Dec 2022	Nov 2022	Nov 2022
Scenario 4	Dec 2021	Feb 2023	May 2023	Mar 2023	Mar 2023
Scenario 5	May 2021	Dec 2021	Jan 2022	Jan 2022	Jan 2022
Scenario 6	May 2021	Apr 2022	Sep 2022	Jun 2022	Jun 2022
Scenario 7	May 2021	Sep 2021	Oct 2021	Dec 2021	Feb 2022
Scenario 8	May 2021	Mar 2022	Sep 2022	Jun 2022	Aug 2022

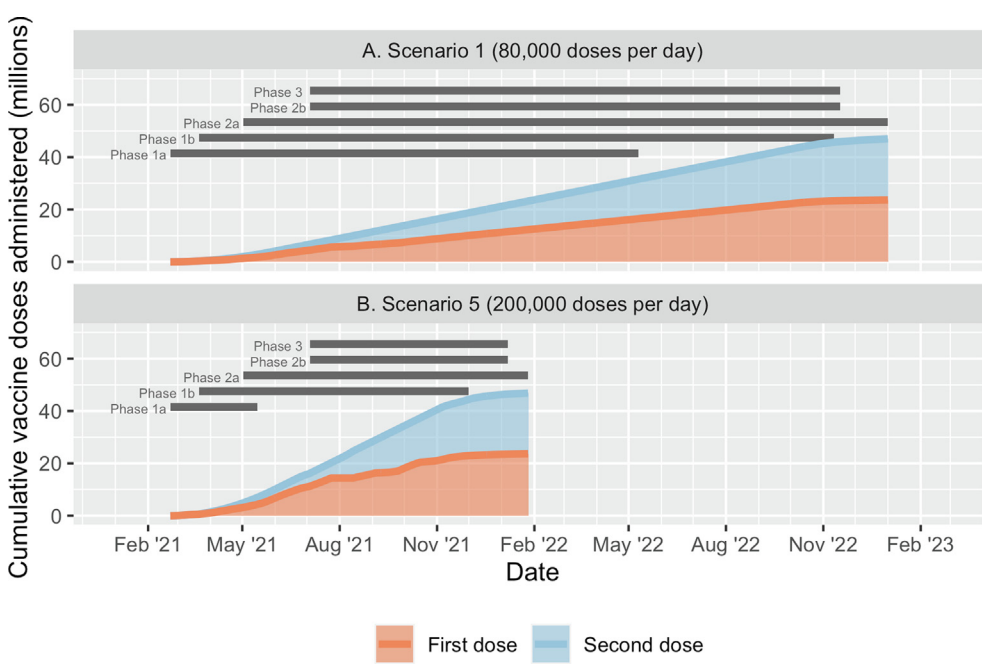

Fig. 1. Cumulative vaccine doses over time.

Phase 1B to reach 90% coverage comparing the low-daily dose Scenarios 3 and 4 (November 2022 versus February 2023). The corresponding delay for the equivalent comparison among the high daily dose scenarios was seven months (September 2021 in Scenario 7 versus March 2022 in Scenario 8). This highlights that vaccine hesitancy can become a bottleneck when the supply of doses is high.

The projections suggest that opening Phases 2B and 3 at an earlier date will speed up the overall rollout slightly, however this moderate improvement comes at the cost of delaying the rollout in higher priority phases. For example, comparing Scenarios 5 and 7, the earlier opening Scenario 5 achieves 90% population coverage of all phases one month earlier (January versus February 2022). However, although Scenario 5 is slightly faster overall, the rollout to the relatively high priority populations in Phase 1B is considerably delayed (December versus September 2021).

The faster rollout scenarios (5 – 8) resulted in variation in the number of daily vaccination doses administered, including a surge beyond the specified capacity that arose when the number of individuals due their second dose exceeded the daily threshold (Supplementary Figure S2). This surge was prominent shortly after the opening of Phase 2B as individuals in Phase 2A returned for

their second dose. Those in Phase 2A received the AstraZeneca vaccine and therefore experienced a longer gap between first and second doses. Troughs in the number of daily doses appeared before the opening of Phase 2B, and these troughs were shorter in scenarios with earlier opening dates (e.g., Phase 5 versus Phase 7).

A rate of 80,000 doses per day was the least optimistic scenario we explored, noting that at rates lower than that duration of the vaccination program would extend to an unreasonable level. For example, at a rate of 50,000 doses administered a day, vaccinating the adult population would take until mid 2023.

4. Discussion

In order to vaccinate all willing adult Australians by early 2021 there will need to be, on average, in the order of 200,000 doses delivered daily from June (including weekends and holidays)—a truly furious pace. This is consistent with other modelling for the state of New South Wales, which shows the need for the delivery of at least 100,000 doses a day for rapid mass vaccination [9].

To gauge the feasibility of such a vaccination administration rate, it is illuminating to consider the COVID-19 vaccination rates

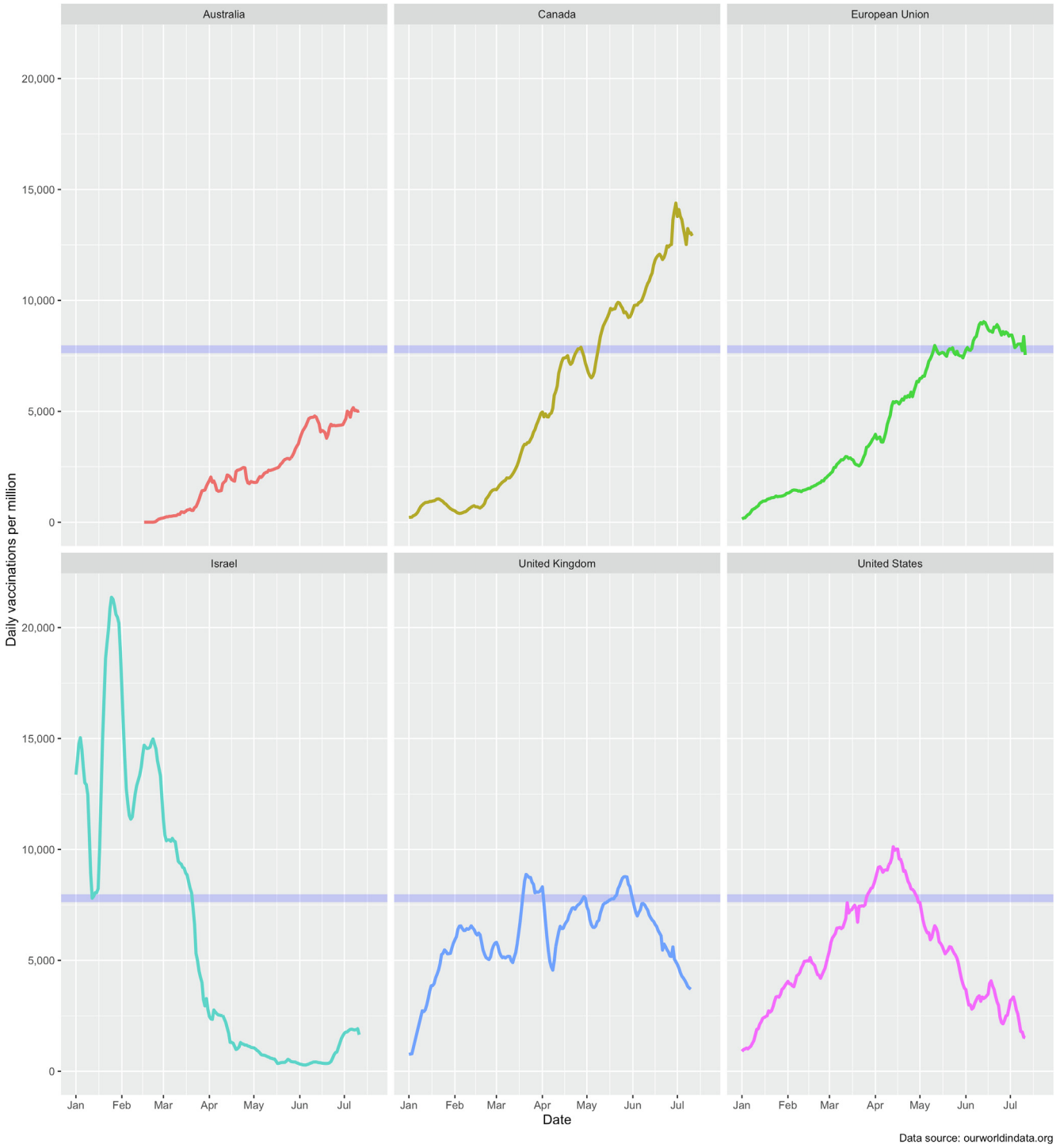

Fig. 2. Daily COVID-19 vaccinations administered per 100 million population for select countries and regions.

currently being reported by other countries which have already begun to roll out their vaccination programs (Fig. 2). The outlier is Israel, where between 7,000 and 20,000 vaccinations per million population have been delivered daily throughout January, February and March. Several factors may have contributed to this success, including a young, largely urbanised population and a strong public health infrastructure. Perhaps most important has been strong logistical planning, including coordination of delivery, ultra-cold-chain storage and staffing [13]. Other countries including the United Kingdom, the United States and Canada, reached and surpassed this rate during April and May. In the US, vaccination was made accessible through the use of incentives.

With a population of 25.7 million in Australia, the figure of 200,000 doses per day from our projections corresponds to approximately 7,800 daily doses per million population. Thus, it does seem possible to vaccinate the Australian population by early 2022, but administration rates considerably higher than those currently being achieved will be needed. Clearly the Australian vaccination program needs to rapidly ramp-up to the required vaccination velocity and then to maintain that pace. To deliver at the required capacity will require dedicated large-scale vaccination sites that are capable of delivering several thousands of doses a week [19], in addition to the participation of GP practices and community pharmacies around the country that are fully enabled and incentivised to participate in the roll out. Anecdotally, many barriers have been reported by GP practices, including restricted supply and onerous bureaucracy in replenishing supplies. Despite this, more vaccines have been delivered by GPs than by mass vaccination centres to date in Australia [14]. Because the AstraZeneca vaccine is not advised for under 50s, the successful rollout is contingent on a steady supply of the alternative procured vaccines (Pfizer, Moderna or Novavax). Demand for these vaccines is likely to increase as the large population of under 50s in Phase 2B and Phase 3 become eligible.

The Australian vaccination program faced several challenges over its first three months. This included limited supply of the imported Pfizer vaccine, delays in production of the locally manufactured AstraZenca vaccine, delays in distribution of available vaccines, and a communication strategy that has not been highly effective. The Federal Government was initially slow to embrace and support State health departments to set up mass vaccination hubs, instead focusing primarily on general practices and community pharmacies as the main distribution hubs [14,15,16]. There is evidence of hesitancy to come forward for vaccination, with higher rates of hesitancy among woman (especially of child-bearing age), people who speak a language other than English, people living outside of capital cities and those in relatively disadvantaged areas [7,8]. Reasons for vaccine hesitancy are primarily driven by concerns about possible adverse side-effects and the blood-clotting issues linked to the AstraZeneca vaccine, with evidence that some people adopting a "wait and see" attitude [8]. There has been a lack of communication strategy to specifically address these identified barriers to date. Our analysis demonstrates that doubling the number of individuals in the two most hesitant categories delayed the rollout by three to four months. This highlights that as well as addressing the vaccine supply issues it is also crucial to promote vaccine willingness in the community. Clear public health communication from a trusted source and targeted messaging to particularly hesitant groups is likely to play a key role in maximizing vaccine uptake [17].

The scale of the mass vaccination program requires a huge investment in human resources, potentially detracting from other services as healthcare staff are redirected to immunisation efforts. This has been mitigated by the establishment of a temporary subregister, allowing retired nurses, doctors and other practitioners to return to the workforce to support the vaccination rollout[18].

Our analysis incorporated a 100 day ramp-up to reflect the relatively slow rollout of the vaccination program over the first three months. If this period lasts longer, or if manufacturing, supply, or other logistical issues limit the daily vaccination rate, our projected rollout times will be optimistic.

5. Conclusion

The length of time it will take to administer two doses of the COVID-19 vaccine to all willing adult Australians depends on a number of factors, but foremost of these is the daily vaccination rate. In order to vaccinate all willing adult Australians by early 2022 it will be necessary to quickly ramp up capacity to administer around 200,000 doses per day. This rate of administration has been achieved in several jurisdictions, including Israel, the United Kingdom and Canada. Dedicated mass vaccination sites, in addition to the planned distribution through GP practices and pharmacies, are necessary to achieve the required capacity. High levels of vaccine hesitancy have the potential to considerably extend the time taken to reach adequate population coverage and may even make it impossible to achieve herd immunity in Australia. Therefore, as well as ensuring a steady supply of vaccine doses and refining the logistics of delivery and distribution, it is necessary to promote vaccine uptake in the community, especially to identified hesitant groups. While encouraging rapid vaccine rollout throughout the population as soon as possible, caution should also be taken to ensure that vulnerable populations are still prioritized.

CRediT authorship contribution statement

Mark Hanly: Conceptualization, Funding acquisition, Data curation, Formal analysis, Software, Visualization, Writing - original draft. **Timothy Churches:** Conceptualization, Funding acquisition, Formal analysis, Software, Visualization, Writing - review & editing, Supervision. **Oisín Fitzgerald:** Conceptualization, Funding acquisition, Formal analysis, Software, Visualization, Writing - review & editing. **C. Raina MacIntyre:** Conceptualization, Funding acquisition, Writing - review & editing, Supervision. **Louisa Jorm:** Conceptualization, Funding acquisition, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Raina MacIntyre has been on an advisory board for COVID-19 vaccine for Seqirus and consulted or done speaking engagements on COVID-19 vaccines for Janssen and Astra Zeneca].

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Appendix A. Supplementary material

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