Notifications decline in pertussis, invasive pneumococcal disease, and invasive meningococcal disease following COVID-19: The potential impact of nonpharmaceutical interventions in Australian states and territories

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Declaration

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at Macquarie University or any other educational institution, except where due acknowledgement is made in this thesis. Any contribution made to the research by others, with whom I have worked with at Macquarie University or elsewhere, is explicitly acknowledged in the thesis.

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Abstract

Background: Following the implementation of COVID-19 nonpharmaceutical interventions (NPIs) in early 2020, substantial declines in notifications of other respiratory pathogens, particularly influenza, have been reported. This study aimed to determine any impact of these measures on pertussis, invasive pneumococcal disease (IPD), and invasive meningococcal disease (IMD) in Australia.

Methods: This study examined notification trends for pertussis, IPD, and IMD in Australian states and territories during the COVID-19 pandemic (2020 and 2021) compared to previous years. For pertussis, the pre-pandemic comparison period was 2017 to 2019. For IPD and IMD, the pre-pandemic comparison period was 2015 to 2019 (2017 was excluded for IMD). For each disease and jurisdiction, monthly notifications for 2020 and 2021 were compared to mean monthly notifications for the pre-pandemic period. Incidence rate ratios were calculated for the annual notification rate for 2020 and 2021 compared to the pre-pandemic mean annual notification rate. Age-stratified rates were calculated for pertussis and IPD.

Results: From early 2020, there was a substantial and sustained decrease in pertussis notifications in all jurisdictions. In 2021, for seven out of eight states and territories all-age pertussis notification rates were over 90% lower than the pre-pandemic period. In Victoria, pertussis notification rates were 84.6% lower (IRR, 0.15 [95% CI, 0.14–0.17]) than the pre-pandemic period. For IPD and IMD, the decrease in notification rates varied considerably between states and territories with Victoria, the state with the longest cumulative lock down period, having the most substantial decrease in 2021 (47.5% for IPD; IRR, 0.53 [95% CI, 0.45–0.61]) (81.4% for IMD; IRR, 0.19 [95% CI, 0.09–0.36]) and second highest decrease in 2020 (61.2% for IPD; IRR, 0.39 [95% CI, 0.33–0.46]) (68.0% for IMD; IRR, 0.32 [95% CI, 0.18–0.55]). Within jurisdictions significant decreases in IPD notifications were most observed among adults aged 25-69 years and 70 years and over than in younger age groups (0-4 years and 5-24 years).

Conclusion: This study has demonstrated the substantial decline in notification rates of three clinically significant conditions – pertussis, IPD, and IMD during time periods and in

jurisdictions most impacted by COVID-19 NPIs. The degree and timing of decrease varied for each disease and between time periods and jurisdictions, suggesting differential impacts of lockdowns and border closures. As these public health measures are progressively lifted across Australia, disease rates should be monitored closely.

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List of abbreviations

ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
ARI	Acute respiratory illness
CI	Confidence Interval
COVID-19	Coronavirus disease 2019
IMD	Invasive meningococcal disease
IPD	Invasive pneumococcal disease
IRR	Incidence rate ratio
IRRs	Incidence rate ratios
MenB	Meningococcal serogroup B
MenC	Meningococcal serogroup C
MenW	Meningococcal serogroup W
MenY	Meningococcal serogroup Y
MenACWY	Meningococcal ACWY
NIP	National Immunisation Program
NPIs	Nonpharmaceutical interventions
NNDSS	National notifiable diseases surveillance system
NSW	New South Wales
NT	Northern Territory
PCR	Polymerase chain reaction
PCVs	Pneumococcal conjugate vaccines
7vPCV	7 valent pneumococcal conjugate vaccine
13vPCV	13 valent pneumococcal conjugate vaccine
Qld	Queensland
RSV	Respiratory syncytial virus
SARS	Severe acute respiratory syndrome
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SA	South Australia
Tas	Tasmania
Vic	Victoria

VPDs	Vaccine preventable diseases
WA	Western Australia
WHO	World Health Organization

1. Literature Review

On March 11, 2020, the World Health Organization (WHO) declared coronavirus disease 2019 (COVID-19) a pandemic.[1] Many countries, including Australia, subsequently adopted a range of public health measures in the form of nonpharmaceutical interventions (NPIs) to control COVID-19 community transmission. These included working from home; business, school, and university closures; cancellation of public events; face masks; physical distancing; travel restrictions; border closures; and quarantine measures.[2, 3]

In addition to curtailing the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2),[4] evidence suggests COVID-19-targeted public health measures have significantly impacted the transmission of other infectious diseases.[5-7] Most notably, respiratory infectious diseases – so termed by sharing a common route of disease transmission, via respiratory droplets[8] – have shown considerable declines, with many countries, including Australia, reporting substantial reductions in common respiratory viruses,[9-13] and respiratory vaccine preventable diseases (VPDs).[14-19]

An abundance of studies have reported significant declines in influenza (up to 99.9%) following the implementation of COVID-19 mitigation measures.[6, 13, 20-27] Data reported to the WHO influenza surveillance database from Australia,[28] Chile, and South Africa showed influenza positivity rates were negligible during the 2020 winter season compared to the previous three years.[20] In the northern hemisphere, Taiwan,[24] Europe,[29] Canada,[26, 30] and the United States,[20] saw sharp declines in test positivity rates and a premature end to the 2019/2020 influenza season within weeks of implementing COVID-19 NPIs. In 2003, instigation of such public health measures during the severe acute respiratory syndrome (SARS) epidemic in Hong Kong was also associated with a reduction in influenza activity.[31]

While influenza has received considerable attention,[6] there are fewer studies examining the effect of COVID-19 NPIs on the respiratory VPDs pertussis,[32-34] invasive pneumococcal disease (IPD),[35-37] and invasive meningococcal disease (IMD).[27, 35, 38, 39] This review will examine epidemiological trends of pertussis, IPD, and IMD in Australia; what is currently known about the potential impact of COVID-19 NPIs on these diseases universally; discuss key research methodologies; examine strengths and limitations of current literature; and address gaps in knowledge that require further investigation. Finally, a rationale for the current study is proposed.

1.1 Pertussis

1.1.1 The epidemiology of pertussis in Australia

Pertussis, also known as whooping cough, is a highly contagious, acute respiratory disease caused by droplet transmission of *Bordetella pertussis* bacterium.[40, 41] Despite high vaccination coverage, Australia experienced a resurgence of pertussis from the early 2000s.[42] Prior to 2012, pertussis was the most frequently notified VPD in Australia.[43, 44] Between 2013 and 2018, it became the second most frequently notified VPD, after influenza.[45]

In Australia, national pertussis notifications display multiannual cycles, with epidemic peaks occurring every 3 to 4 years.[41, 45] Peaks in national notifications have been observed between 1997 and 1998; 2001 and 2002; 2005 and 2006; and 2009 to 2012. Most recently, there was a national peak between 2015 and 2016.[45] Pertussis also shows a seasonal pattern with peak notifications occurring in the spring and summer months, including in tropical areas.[41] Peaks typically begin in early November for the general population with delays until January or February for children under 5 years of age.[41]

Between 1995 and 2007, annual pertussis notifications across Australia showed variation at the national level with rates ranging from 23.1 per 100,000 to 58.1 per 100,000.[43, 44] Between 2008 and 2011, pertussis rates increased steadily, resulting in the largest national pertussis epidemic peaking at 173.3 notifications per 100,000 in 2011.[41, 44] Between 2011 and 2014, national notifications fell to 50.7 per 100,000 in 2014.[44, 45] From 2014, notifications increased sharply to reach a national epidemic peak of 94.8 per 100,000 in 2015, which declined in 2016 to 83.2 per 100,000.[45] From 2016, notifications further declined to 50.4 per 100,000 in 2018.[45]

With regards to age-specific rates, between 1995 and 2005 the highest pertussis notification rates were consistently seen among infants under 6 months of age.[43] During this time there was an increasing trend in the proportion of notifications among those aged 10-19 years; 20-59 years; and 60 years and over, while the proportion of notifications among children aged under 1 year; 1-4 years; and 5-9 years showed a decreasing trend.[43]

During the epidemic period, between 2008 and 2011, the highest notification rates occurred among infants under 6 months of age and children aged 5-9 years.[44] Between 2007 and 2011, pertussis notification rates among children aged under 15 years increased steeply, overtaking and more than doubling rates of those aged 15 years and over by 2009.[44] In 2011, children aged 5-9 years had the highest notification rates, reaching 556.2 per 100,000.[44]

Between 2013 and 2018, the highest pertussis notification rates were seen among children aged 9-11 years (264.2 per 100,000 for females; 232.5 per 100,000 for males), followed by those aged 3 years (159.2 per 100,000 for females; 156.2 per 100,000 for males).[45] During this period there was a substantial decline in notifications among infants under 2 months of age, which decreased by 61% from 132.3 per 100,000 in 2015 to 51.4 per 100,000 in 2018, to reach the lowest incidence of all age groups under the age of 15 years in 2018.[45] The introduction of jurisdictionally funded maternal pertussis vaccination programs between 2014 and 2015 is likely to have played a significant role in the observed decrease in pertussis notifications among young infants.[45, 46] Furthermore, the re-introduction of the 18-month booster dose in 2016 and the recommendation in 2013 that adults over 65 years of age receive a booster may have also influenced pertussis notification rates in this age group.[45]

The highest morbidity and mortality from pertussis infection occurs in infants under 6 months of age, who often require hospitalisation.[47] Between 2013 and 2017, Australian infants under 2 months of age and 2-3 months of age had the highest mean annual pertussis hospitalisation rate of any age group (143.2 per 100,000 and 137.8 per 100,000, respectively).[45]

For Aboriginal and Torres Strait Islander infants (hereafter respectfully referred to as Indigenous), between 2013 and 2018 notification rates for children under 5 years of age were higher than non-Indigenous children across all age groups (under 2 months; 2-3 months; 4-5 months; 6-11 months; 12-17 months; and 18 months to under 5 years). The highest notification rates were seen in Indigenous infants 2-3 months of age, which were six times higher than that of non-Indigenous infants in this age group (IRR, 6.0 [95% CI, 4.7–7.6]: 856.8 per 100,000 Indigenous vs. 142.4 per 100,000 for non-Indigenous).[45] Hospitalisation rates for Indigenous children under 5 years of age were substantially higher than non-Indigenous children, with infants aged 4-5 months over eight times more likely to be hospitalised (IRR 8.1, [95% CI, 5.5 – 11.8]: 424.6 per 100,000 Indigenous vs. 52.6 per 100,000 for non-Indigenous).[45]

On a state and territory level, there is recognisable variation in pertussis epidemiology, with evidence of geographical differences regarding the timing and amplitude of epidemic peaks.[43, 45] Between 1995 and 2005, epidemic cycles in New South Wales, Queensland and South Australia followed similar patterns. By contrast, regions that have a lower population density and/or are geographically isolated such as the Northern Territory, Tasmania and Western Australia, all had longer inter-epidemic periods.[43]

A similar pattern was also observed during the 2008 to 2011 pertussis epidemic. The Northern Territory had an earlier epidemic (2008 to 2009), followed by South Australia (2009 to 2010) which had both the highest and second highest annual pertussis notification rate of 453.6 notifications per 100,000 in 2010 and 332.6 per 100,000 in 2009.[44] Most other jurisdictions peaked between 2010 and 2011. Western Australia (2011 and 2012) and Tasmania (2012) were the last to reach epidemic levels.[44]

Three key factors are thought to have played a role in the 2008 to 2011 pertussis epidemic.[44] First, waning immunity among older children following immunisation with the acellular vaccine (which replaced the whole cell vaccine nationally in 1999, and in South Australia and the Northern Territory from 1997), may have played an influential role in the epidemic.[44, 48]

Second, in 2003 the 18-month booster dose was removed from the National Immunisation Program (NIP) schedule. This amplified the impact of the acellular vaccine's shorter immunity period by resulting in an extended interval between doses from 6 months to 4 years of age.[44]

Finally, the expansion of more sensitive polymerase chain reaction (PCR) testing into primary care from 2007, may have also contributed to the substantial increase in pertussis notifications during this time.[41, 44, 48] Research has shown pertussis notifications were over eight times higher (95% CI, 8.5–9.0) in the post-PCR era (2007 to 2013) compared to the pre-PCR era (1991 to 2006).[48] Nonetheless, as pertussis hospitalisation rates increased comparably to notification rates between 2007 and 2009, and PCR testing has been widely utilised in hospitals since 2000, it is unlikely that the increase in pertussis notifications was solely due to increased PCR testing in primary care.[44]

Between 2013 and 2018, all states and territories experienced a decline in their respective mean notification rates compared to the previous 7-year period. This ranged from 65% in Queensland (122.5 per 100,000 to 42.7 per 100,000), to just over 60% in South Australia (178.5 per 100,000 to 69.0 per 100,000) and the Northern Territory (116.4 per 100,000 to 44.4 per 100,000), to a modest 6% decline in Western Australia (66.9 per 100,000 to 62.8 per100,000).[45]

During the 2015 and 2016 epidemic, the national peak in pertussis notifications mainly indicated disease activity in New South Wales and the Australian Capital Territory. New South Wales recorded the highest annual notification rate in 2015 (160.8 per 100,000) and 2016 (140.1 per 100,000).[45] The Australian Capital Territory recorded the second highest notification rate in 2015 (123.0 per 100,000) and 2016 (125.5 per 100,000).[45, 49] Regarding jurisdictional timing, Victoria and Western Australia had an earlier epidemic (2014 to 2015), followed by the Australian Capital Territory and New South Wales (2015 to 2016), and the Northern Territory (2016). South Australia had the longest epidemic period (2015 to 2017), and Tasmania (2018) was the last to reach epidemic levels.

1.1.2 *The potential impact of COVID-19 measures on pertussis*

International studies have reported substantial, unprecedented declines in pertussis cases following the implementation of COVID-19 NPIs.[32-34] A large study examining national surveillance data from England, reported a rapid and sustained drop in pertussis cases that coincided with COVID-19 lockdown restrictions.[33] From July 2020 to June 2021, pertussis activity decreased significantly across all age groups compared to the 2014 to 2019 average, particularly among infants under 1 year of age (98%) (IRR, 0.02 [95% CI, 0.00–0.06]), and children aged 5-14 years (99%) (IRR, 0.01 [95% CI, 0.0–0.02]). For children aged 1-4 years there was a 94% decrease in pertussis incidence (IRR, 0.06 [95% CI, 0.02–0.15]).[33] Despite expecting an epidemic peak, England recorded the lowest number of pertussis cases in the last decade.[33]

In Sweden, the number of notifiable pertussis cases in infants under 1 year of age decreased from an average of 21 quarterly cases in January 2014 to March 2020, to an average of 1 case per quarter from April 2020 to September 2021.[34] Compared to the 2015-2019 average, the number of notifications in 2020 fell by 75.6%.

In France, time series analysis using the data from 2013 to 2020 estimated an 89.9% decrease (IRR, 0.10 [95% CI, 0.04–0.26]) in pertussis cases after a national lockdown was implemented on March 16, 2020.[32] This substantial reduction had not been seen since French pertussis surveillance began in 1996.[32] While it has not yet been peer reviewed, the study reported a significant decline in the incidence of pertussis across all ages, particularly among adults 18 years and older (93.6%) (IRR, 0.06 [95% CI, 0.03–0.17]) and children aged 6-17 years (92.7%) (IRR, 0.07 [95% CI, 0.03–0.20]). For children aged 0-5 years the reduction was comparatively moderate (78.3%) (IRR, 0.22 [95% CI, 0.08–0.56]), and analogous to the decrease observed in hospitalised pertussis cases among infants under 1 year of age (78.4%) (IRR, 0.22 [95% CI, 0.07–0.66]).[32] While these three studies utilised different methods of analysis, they all focused primarily on pertussis, reporting similar falls in disease activity.

In contrast, a study conducted in The Republic of Korea, investigating the incidence of several respiratory infectious diseases, found no statistically significant difference in pertussis notifications between February and July 2020 among adults aged 18 years or older when compared to the 2016 to 2019 average (p=0.24).[18] However, a large decrease was observed in children aged 7-17 years (79%, p=0.03), followed by those aged 0-6 years (64%, p=0.01).[18] Another Republic of Korea study, which did not stratify by age, found a 28% (95% CI, 0.03–0.15) decrease in pertussis notifications between January and June, 2020, compared to the average between 2015 and 2019.[14] As both studies used the same centrally notified data source, the variation in results is likely due to differences in analytical methods, and length of the study and comparison periods.[50]

In Australia, the potential impact of COVID-19 NPIs on pertussis has received little attention. A Central Queensland study reported an 87% reduction in pertussis notifications during 2020 compared to the 2015 to 2019 average.[51] In Victoria, there was report of a 57% decrease in pertussis notifications in 2020 compared to the 2015 to 2019 mean.[52] However, for both these studies the data were not age stratified. In the grey literature, an Australian Productivity Commission report found national pertussis notifications declined by 98.6% among children aged 0-14 years in 2020/21 (2.4 per 100,000) compared to the previous 5-year average (166.9 per 100,000).[53, 54] The report did not stratify children into younger age groups or provide data on adult age groups.

1.2 Invasive pneumococcal disease and meningococcal disease

1.2.1 The epidemiology of invasive pneumococcal and meningococcal disease

Invasive pneumococcal and meningococcal disease are caused by the spread of *Streptococcus pneumoniae* (pneumococcus) and *Neisseria meningitidis* (meningococcus) from the nasopharynx, to other normally sterile sites such as blood and cerebrospinal fluid.[49] Transmitted through respiratory droplets, these diseases can cause bacterial pneumonia, meningitis, and sepsis, contributing to significant global morbidity and mortality amongst all age groups, particularly in infants (aged less than 5 years), adolescents, and older adults (aged 65 years and over).[35, 55] In 2016, pneumococcus was believed to cause over 1 million annual pneumonia deaths worldwide.[56] Furthermore, there were over 300,000 deaths from meningitis, with meningococcus a major cause, and pneumococcus having the highest rates of long-term disability.[57]

In Australia, IPD and IMD exhibit a seasonal pattern, with notifications traditionally increasing over the winter months for IPD, and mid-winter and early spring for IMD.[58-60] As epidemiological and clinical evidence suggest viruses such as influenza and respiratory syncytial virus (RSV) increase an individual's susceptibility to invasive bacterial disease, it has been hypothesised these are important drivers of seasonal IPD and IMD activity.[27, 61-63]

1.2.1.1 Invasive pneumococcal disease in Australia

Over the past 20 years, the changing landscape of IPD notifications in Australia has been largely influenced by the introduction of pneumococcal conjugate vaccines (PCVs) for children; the evolution of distinct PCV periods; and vaccination efficacy.[64, 65] Pneumococcal conjugate vaccines are composed of different types of pneumococcal bacteria (serotypes), which provide specific protection against the serotypes included in the vaccine construct.[66]

Following the introduction of PCVs to the NIP in the early 2000s, Australia initially had substantial declines in IPD notifications, particularly among high-risk age groups (children aged less than 1 year and 1-4 years) directly targeted by the program.[65] Due to a later gradual increase in IPD notification rates, particularly among infants, in 2011 the PCV was redesigned to include a broader range of serotypes.[67]

The first PCV program, a 7-valent PCV (7vPCV) administered at 2, 4, and 6 months of age, was in introduced to the NIP in 2001 and recommended for all Indigenous infants.[64] In 2005, the program was expanded to a universal program that targeted all infants.[64] Following the universal 7vPCV rollout, when compared to the pre-universal-7vPCV period (2002 to 2004), substantial declines in IPD notification rates were observed among all age groups, Indigenous and non-Indigenous. Children aged less than 1 year decreased by 71% (24.5 per 100,000 between 2005 to 2007 compared to 83.2 per 100,000 between 2002 to 2004)(IRR, 0.29 [95% CI, 0.25–0.35]), and children aged 1-4 years decreased by 65% (17.1 per 100,000 between 2005 and 2007 compared to 50.3 per 100,000 between 2002 to 2004) (IRR, 0.35 [95% CI, 0.32–0.39]).[65]

Between 2009 and 2011, IPD rates gradually increased, mostly signifying an increase in rates among Indigenous children aged less than 5 years, which increased by 37% (73.4 per

100,000 in 2011 compared to 53.5 per 100,000 in 2010) (IRR, 1.37 [95% CI, 0.89–2.15]).[67] Due to the emergence of non-7vPCV serotypes, the 7vPCV was replaced by the 13-valent PCV (13vPCV) in mid 2011.[64, 65] From mid 2011 to 2012, IPD notifications decreased rapidly across all age groups, with rates among Indigenous children aged less than 5 years falling by 33% (37.1 per 100,000 in 2012 compared to 73.4 per 100,000 in 2011).[67]

Between 2013 and 2014, the decrease in IPD rates was less evident. Notifications gradually increased across all age groups between 2015 and 2018, including among high-risk groups such as Indigenous Australians, children aged less than 5 years, and adults aged 50 years and over.[58, 59] With evidence of progressively mounting 13vPCV vaccine failures, particularly in children over the age of 12 months, the 13vPCV schedule was changed in 2018 from three doses administered at 2, 4, and 6 months of age, to two infant doses administered at 2 and 4 months of age, followed by one booster at 12 months of age.[64]

In 2019, among non-Indigenous Australians the number of IPD notifications continued to be highest in children aged less than 5 years and among older adults, particularly those aged 50 years and over.[58, 68] In the third quarter of 2019, for Indigenous Australians (who accounted for 13% of reported cases), IPD notifications and were highest in children aged less than 5 years and adults aged 40-44 years.[58] In 2019, the highest proportion of IPD notifications reported among Indigenous Australians compared to non-Indigenous Australians were recorded in the Northern Territory, followed by Western Australia.[58, 59, 68]

On a state and territory level, compared to other jurisdictions the Northern Territory has consistently had the highest rates of IPD.[49, 67] Between 2012 and 2015, it had the highest mean annual notification rate of 24.2 per 100,000, well above the second highest mean rate of 8.0 per 100,000 in Tasmania and the national mean of 6.9 per 100,000.[49] Between 2015 and 2019, the Northern Territory continued to hold the highest mean rate of 22.82 per 100,000.[69] This was considerably larger than the second highest mean rate of 9.4 per 100,000 in South Australia and the national mean of 6.9 per 100,000.[69]

With regards to IPD epidemics, an outbreak of IPD in the Northern Territory, Western Australia, and Queensland in 2011 triggered a serotype 1 IPD epidemic, in which notifications among Indigenous Australians (16.4 per 100,000) were 80 times higher than non-Indigenous (0.2 per 100,000).[65]

1.2.1.2 Invasive meningococcal disease in Australia

While the incidence of IMD in Australia is low, it is a disease of considerable public health concern.[60] Since the early 2000s, progressive vaccine rollouts have played an important role in reducing disease activity.[27]

In 2002, Australia experienced a peak in IMD notifications at 3.54 per 100,000.[60] Following the introduction of the meningococcal serogroup B (MenB) vaccine to the NIP in 2003, notifications steadily declined to their lowest point of 0.6 per 100,000 in 2013, before progressively increasing to 1.5 per 100,000 notifications in 2017.[70, 71] This later increase was attributed to the emergence of new meningococcal serogroups, W (MenW) and to a lesser extent Y (MenY), such that MenW became the dominant serogroup nationally between 2016 and 2017.[72] In 2018, following the implementation of targeted vaccination programs, national IMD notifications decreased to 1.1 per 100,000, further decreasing in 2019 to 0.8 per 100,000.[71]

With regards to age-specific rates, recent surveillance data has shown the highest incidence of IMD in Australia occurs in children under the age of 5 years, followed by adolescents aged 15-19 years, and young adults aged 20-24 years.[73]

Historically, the incidence of IMD is higher among Indigenous Australians than non-Indigenous Australians. Between 2006 and 2015, all-age Indigenous MenB notification rates were nearly four times higher than those of non-Indigenous Australians.[70] In 2017, there was a large outbreak of MenW among the Indigenous paediatric population of Central Australia such that notifications among these Indigenous infants peaked at 10.9 cases per 100,000. [74]

Other jurisdictions also had an increase in notifications in 2017 but to a lesser extent, with Tasmania peaking at 3.1 per 100,000 followed by South Australia at 2.1 per 100,000.[69] Consequently, jurisdictional meningococcal ACWY (MenACWY) vaccination programs were employed across targeted age groups, in addition to replacing the MenC vaccine on the NIP in 2018.[71] In 2018 and 2019, notifications in the Northern Territory decreased to 4.5 per 100,000 and 2.5 per 100,000 respectively.[69] In 2019, the highest notification rates were in the Northern Territory (2.0 per 100,000), and the lowest rates were in the Australian Capital Territory (0.2 per 100,000).[73]

1.2.2 The potential impact of COVID-19 measures on invasive pneumococcal and meningococcal disease

Since the COVID-19 pandemic, Australian and international studies have reported varying declines in IPD and IMD ranging from 17% to more than 80%.[19, 35, 39, 51] An extensive study, examining surveillance data from over 20 countries across the northern and southern hemisphere (not including Australia), reported a substantial and continued reduction in IPD and IMD between March and May 2020 compared to the same period in 2018 and 2019.[35] This trend was temporally associated with the introduction of NPIs in each country. The combined incidence of IPD reduced by 82% (IRR, 0.18 [95% CI 0.14–0.23]) eight weeks after containment measures were identified.[35] As IMD had lower case numbers, the authors did not apply the later meta-analysis to this data.[35]

A study evaluating the impact of national lockdown on IMD in France found a significant reduction in disease activity.[38] Only 23 notifications were seen between March and May 2020, compared to 73 in 2018 and 68 in 2019 during the same period.[38] In Taiwan, meningococcal meningitis notifications reduced by a modest 16.7%.[19] The reduction in IPD notifications was greater at 45.2%.[19] In Singapore, IPD notifications from an adult tertiary care hospital fell to their lowest point of 8 between January and June 2020, compared to a 2010-2019 median of 14 during the same period.[36]

Invasive disease activity amongst susceptible groups such as children and older adults has also been explored. A study from England reported a decrease in national paediatric hospital admissions (aged 0-14 years) between March 2020 and February 2021 for IPD and IMD, 60% (95% CI, 0.29–0.55) and 69% (95% CI, 0.2–0.47), respectively, compared to the 2017/18 to 2019/20 average.[16] This occurred across all demographic subgroups and irrespective of underlying comorbidities.[16] Moreover, a study examining English national surveillance on IMD over a shorter five month period (April to August 2020) demonstrated an 80% (IRR, 0.20 [95% CI, 0.07–0.58]) reduction in cases among children aged 5-14 years, and a modest 56% (IRR, 0.44 [95% CI, 0.25–0.78]) reduction among children under the age of 5 years, compared to the same period in 2019.[39] The greatest decline however, was seen among older adults, with those aged 65 and over having an 86% (IRR, 0.14 [95% CI, 0.06–0.32]) reduction in IMD activity.[39]

Regarding IPD, one study found a 30% decrease in national IPD notifications in England among children under the age of 16 years (IRR, 0.71 [95% CI, 0.11–10.00]); adults 16-64 years (IRR, 0.65 [95% CI, 0.11–3.79]); and older adults 65-84 years (IRR, 0.72 [95% CI, 0.29–1.74]) and 85 years and over (IRR, 0.69 [95% CI, 0.42–1.76]), during 2019/20 compared to the previous 12 months. However, the decrease observed was not significant for any age group.[37] In Korea, IPD notifications from February to July 2020 among young children (0-6 years) and adults 18 years and over reduced by 52% and 41% respectively (p=0.02), compared to the 2016-2019 average. However, the reduction in children and adolescents aged 7-17 years was not significant (p=0.08).[18]

Studies examining the impact of COVID-19 mitigation measures on IPD in Australia are lacking. One study that looked at IPD notifications in the jurisdiction of Central Queensland from April to September 2020, reported a 17% reduction compared to the 2015 to 2019 mean.[51] Another study, which examined IPD notifications in Victoria in 2020, reported a 58% decrease in notifications compared to the 2015 to 2019 mean.[52]

Regarding IMD, a recent study has reported record declines in Australian IMD notifications during 2020 and the first quarter of 2021.[27] However, the study, which reported a timeline of national IMD cases from 1998 to 2021, did not specify a proportionate decrease in relation to a pre-pandemic period.[27] Furthermore, it did not examine cases within states and territories. Another study, which also looked at national IMD notifications in Australia early in the pandemic, found a 51% decrease in the first 6 months of 2020 when compared to the 2015 to 2019 mean.[75] Nonetheless, as this research was solely conducted on a national level, trends in IMD notifications for individual states and territories were also not presented. Only one study has looked at IMD notifications on a state-level, reporting a 70% decrease in notifications in Victoria in 2020 when compared to the 2015 to 2019 mean.[52]

1.3 Primary methodologies, strengths, and limitations of current research

Research examining the impact of COVID-19 on other respiratory infectious diseases has used ecological studies to compare the incidence of respiratory VPDs within a population before and after the implementation of COVID-19 NPIs.[76] As NPIs are designed and implemented at the population level,[77] it follows that ecological studies are used to evaluate responding disease activity across the population. Furthermore, given that pandemic response measures are public health interventions, often with varying degrees of enforced compliance, controlled trials or observational studies of these interventions are logistically difficult if not impossible and are subject to extensive ethical and logistical hurdles.[77, 78]

Almost all reviewed studies examined trends in notifiable diseases data, encompassing primary-care, hospital, or laboratory surveillance.[14, 15, 18, 19, 27, 33-39, 51, 52, 75] Such data are advantageous for public health research, often being easily accessible and providing a timely indication of changes in disease activity.[76] Many authors compared the annual pre-pandemic mean (often for the previous three, four or five years) to cases during the pandemic, either through rate ratios with 95% confidence intervals,[14, 16, 18, 33] or a direct comparison of case numbers.[34, 51, 52, 75] One study used the median of the previous 10 years as the pre-pandemic comparison.[36] Other methods of analysis included interrupted time series (ITS),[15, 32, 35] and Chi-squared test.[38]

Interrupted time series design is particularly suited for evaluating the effectiveness of health interventions implemented at the population level when there is clear differentiation of the pre-intervention and post-intervention period, such as before and after the introduction of NPIs.[79] Although ITS can be used to adjust for time-varying confounders and seasonal trends, it is not suitable for studies with few time points or where case numbers are very low, as may be the case for conditions such as IPD and IMD.[79]

In contrast, comparison of an aggregate 3–5-year pre-pandemic mean to the post-pandemic period may be more suited to data collected across a shorter period for which cases or notifications are ascertained and where the data are categorised over months rather than weeks or days. This method is equally suitable for evaluating the effectiveness of health interventions implemented at the population level. As this method is frequently used it enables comparison between studies; it allows pre-pandemic and post-pandemic comparison which is easily interpretable through a rate ratio; and the aggregate mean may also be adjusted to exclude disease outbreaks.

Some authors only compared disease activity during the pandemic with the previous year.[19, 37, 39] In the event of outbreaks or where epidemic peaks occurred, a short comparison period with higher levels of disease activity could lead to an overestimation of the true association between exposure and outcome. Conversely, if the preceding year had unusually low levels of disease, the effect of NPIs might be overlooked. An extended period of comparison would negate some of these impacts.

There were five studies that stratified by age, [18, 32, 33, 37, 39] and two that analysed paediatric data from disease notifications or hospital admissions.[16, 34] As pertussis has the highest burden among infants,[40, 45] and those at the extremes of age are at increased risk of developing invasive diseases,[49] age stratification is an important methodological element in this field of research.

Although ecological analysis cannot prove causality and is often subject to confounding,[76] the concordance in epidemiological trends temporally associated with NPIs across numerous countries is persuasive.[20] Furthermore, in view of SARS-CoV-2, *B. pertussis*, pneumococcus, and meningococcus sharing a common route of respiratory transmission,[33, 35, 80] the ability for COVID-19-targeted NPIs to effect the transmission of other respiratory VPDs has high biological plausibility.

Nonetheless, consideration must also be given to the possibility of under-reporting caused by disruption in disease testing capacity, alterations to testing practices, and changes in pandemic health-seeking behaviour.[6, 33, 35] Evidence of a considerable yet transient decline in pertussis testing was observed in England during mid-2020.[33] However, after a substantial increase in testing activity from September 2020 onward, pertussis positivity rates still remained exceptionally low until July 2021.[33] Furthermore, it has been proposed that changes in testing activity among young infants would be minimal as they are more likely to present with serious symptoms.[32, 34] Accordingly, age stratified analysis that considers the incidence of pertussis in this cohort is perhaps a more accurate representation of disease activity, being less subject to biases of under-reporting. In contrast, since invasive diseases are a medical emergency and often require hospital admission, it is highly likely that patients of all ages with IPD or IMD will seek medical care.[35] Therefore, the incidence of these diseases is less likely to be underestimated. Correspondingly, some authors have reported testing and surveillance activity equivalent to pre-pandemic levels.[35, 36]

1.4 Gaps in the literature

Numerous studies have described significant declines in influenza activity following the instigation of COVID-19 public health measures.[6, 13, 20-27] Comparatively fewer however, have focused primarily on other respiratory VPDs such as pertussis,[32-34] IPD,[35-37] and IMD.[27, 35, 38, 39] Furthermore, many studies did not report age stratified data for these diseases.[14, 15, 19, 27, 35, 36, 51] Age stratification is potentially advantageous for two reasons. First, it highlights changes in disease activity amongst high-risk age groups. Second, in the case of pertussis, it may provide a more accurate representation of post-pandemic disease activity compared to crude rates.

In Australia, a comprehensive analysis of the effect of COVID-19 public health measures on the incidence of pertussis and IPD is lacking. To date, only two studies, which did not age stratify, have examined pertussis and IPD notifications in Central Queensland and Victoria.[51, 52] Furthermore, as these studies were conducted on a regional-level or state-level, there is a need for additional research examining the impact of COVID-19 NPIs on pertussis and IPD across other states and territories. Finally, while national-level studies on IMD have been conducted, there is also paucity of research examining the impact of COVID-19 measures on IMD notifications across Australian states and territories. To date, only one study has looked at IMD notifications following COVID-19 restrictions in Victoria.[52]

1.5 Rationale for the current study

After numerous countries adopted COVID-19-targeted NPIs in early 2020, significant reductions in the activity and notifications of other respiratory VPDs have been reported. While the decrease in influenza has received international attention,[9, 13, 20, 24] research in Europe and Asia investigating pertussis, IPD, and IMD has also shown substantial decreases in disease activity.[14, 18, 19, 32-34, 36-39] Notably, pertussis notifications in some of these jurisdictions have shown record falls. Nevertheless, consideration must also be given to under-reporting, emphasising the importance of age stratified analyses.

In Australia, there is limited research on the impact of COVID-19-targeted NPIs on pertussis, IPD, and IMD notifications. Furthermore, research conducted across individual states and territories and among age groups at increased risk of infection or severe disease is lacking. As there are distinct interjurisdictional differences in the epidemiology of these diseases, evaluation of national notification rates alone may potentially overlook varying trends within individual states and territories. In the interests of guiding future public health messaging, further research encompassing all states and territories is needed to establish how pandemic response may have impacted the incidence of these infectious diseases.

While some NPIs in Australia were instigated at a national level, others were managed at a jurisdictional (state/territory) basis. Although it is not possible to establish which specific components of NPIs may have the greatest impacts on disease activity in an ecological observational study, comparison of changes in notification rates between jurisdictions may provide an opportunity to determine the differential impacts of certain NPIs in potentially reducing disease transmission.

The preliminary objective of this study is to establish a timeline of COVID-19 NPIs in Australia for each state and territory between 2020 and 2021. The primary objective of this study is to evaluate the impact of NPIs on key respiratory infectious diseases across Australia by comparing notification data for pertussis, IPD, and IMD in the pre-pandemic period to the data in 2020 and 2021, nationally, by jurisdiction, and by age group.

2. Methods

2.1 Study Design

This descriptive study examines notification data trends for pertussis, IPD, and IMD during the COVID-19 pandemic period (January 1, 2020, to December 31, 2021) compared to previous years. For pertussis, the 3-year period prior to the pandemic (2017 to 2019) served as the pre-pandemic comparison period and excluded 2015 and 2016 as these years were epidemic years when 94.8 per 100,000 and 83.2 per 100,000 notifications were reported nationally.[45] For IPD, the 5-year period prior to the pandemic (2015 to 2019) served as the pre-pandemic comparison period. For IMD, the 4-year period prior to the pandemic served as the pre-pandemic comparison period (2015 to 2019, excluding 2017). The year 2017 was excluded due to an IMD outbreak in Central Australia when 10.9 cases per 100,000 were reported among Indigenous Australians under 15 years of age.[74]

2.2 Data

In Australia, pertussis, IPD, and IMD are notifiable diseases under each state and territory's respective public health legislation. Registered medical practitioners and pathology laboratories are required to report these conditions to state and territory health departments, which supply de-identified notification data to the Commonwealth's National Notifiable Diseases Surveillance System (NNDSS).[69] Monthly notification data stratified in five year age groups for pertussis, IPD, and IMD between January 2015 and December 2021, were provided by the NNDSS on May 17, 2022.

2.3 Timeline of state and territory public health measures

Chronologies of COVID-19 public health measures for each state and territory (stay at home orders [lockdowns], mandatory wearing of face masks outside the home, and hard interjurisdictional border closures) were sourced from reports published by Parliament of Australia,[81] the Australian Bureau of Statistics (ABS),[82] and state and territory Government media releases.

2.4 Analysis

Descriptive statistics were used to summarise notification numbers and rates of pertussis, IPD, and IMD nationally and by state/territory. For each disease and jurisdiction, we compared the mean monthly notifications for the pre-pandemic period to notifications for each month in 2020 and 2021. For IPD and IMD, due to a low number of cases, notifications for the Australian Capital Territory were combined with New South Wales. Annual notification rates per 100,000 population were calculated by dividing the total annual notifications for each disease by the mid-year estimated population of each jurisdiction and multiplying by 100,000. Population data were sourced from the ABS Quarterly Population Estimates.[83] Incidence rate ratios and 95% confidence intervals (IRR 95% CI) were calculated to compare rates between periods.

For pertussis, IRRs were calculated for the annual notification rate for 2020 and 2021 compared to the mean annual notification rate for 2017 to 2019. For IPD, IRRs were determined for the annual notification rate for 2020 and 2021 compared to the mean annual notification rate for 2015 to 2019. For IMD, IRRs were determined for the annual notification rate for 2020 and 2021 compared to the mean annual notification rate for 2015 to 2019, excluding 2017.

To assess the impact of the exclusion of epidemic and outbreak years for pertussis and IMD, a sensitivity analysis was conducted in which IRRs were determined for annual notification rates for 2020 and 2021 compared to mean annual notification rate for all five years (2015 to 2019).

For each jurisdiction, additional age-stratified notification rates and IRRs were calculated for pertussis and IPD. For pertussis, notification rates and IRRs were calculated for the age groups 0-4, 5-14, 15-24, 25-69, and ≥ 70 years. For IPD, the age groups were 0-4, 5-24, 25-69, and ≥ 70 years.

Data were analysed using Stata 17.0.

2.5 Ethics

Institutional ethics approval was provided by the Macquarie University Human Research Ethics Committee (HREC520221151037299).

3. Results

3.1 Public health interventions

Public health interventions that were considered to have potential impacts on pertussis, IPD, and IMD are summarised in Figure A1 in Appendix A. In Australia, a national lockdown was implemented at the beginning of the first wave of the COVID-19 pandemic on March 23, 2020. This comprised a series of COVID-19-targeted NPIs such as working from home; on-line education; closure of non-essential businesses such as retail and hospitality; social distancing; and density limits.[81, 82] Lockdown restrictions were progressively eased across all jurisdictions between May 11 and May 18, 2020.[82] In Victoria, a second lockdown was implemented on July 8, 2020, which lasted for 111 days. In 2020, Victoria had the highest number of lockdown days overall of any state or territory (160 days) and enforced some of the most stringent public health restrictions.[84]

In April 2020, Western Australia and Queensland implemented a hard border closure to all other Australian states and territories.[81] In Western Australia, the hard border closure lasted for 223 days, transitioning to a fluctuating 'controlled interstate border' on November 14, 2020, based on whether other states and territories met specific COVID-19 epidemiological criteria.[85] Western Australia lifted its controlled border on March 3, 2022.[86] In Queensland, the hard border closure lasted for 100 days, and was lifted on July 10, 2020.[81]

Throughout 2021, a series of further state and territory-level lockdowns were implemented (a timeline of state and territory public health measures showing lockdowns, mask mandates, and hard interjurisdictional border closures is presented in Table A1 in Appendix A). Victoria and New South Wales had the longest lockdown periods in 2021 of 108 and 107 days, respectively. Unlike 2020 – where Victoria was the only state to implement mandatory mask wearing during their second lockdown – in 2021, all states and territories enforced mandatory mask wearing outside the home during their respective lockdown periods.

During 2020 and 2021, notification rates for all three conditions of interest decreased. (Figure 1).

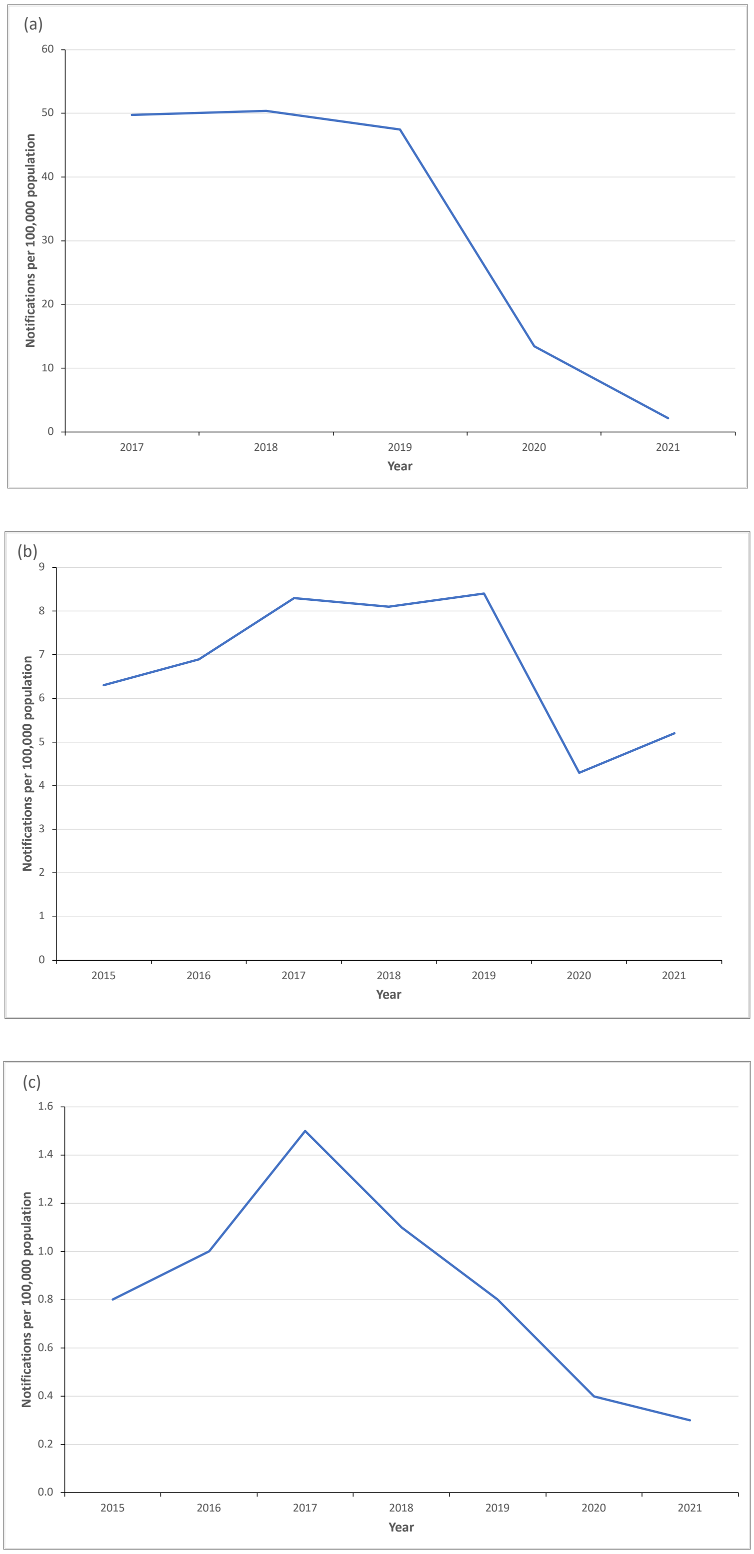

Figure 1. National notification rates of pertussis (a) (2017 to 2021), invasive pneumococcal disease (b) (2015 to 2021), and invasive meningococcal disease (c) (2015 to 2021), Australia.

3.2 Pertussis

3.2.1 Australia

Between 2017 and 2021, a total of 40,850 pertussis notifications were recorded nationally. During this period all-age annual notification rates were stable between 2017 (49.8 per 100,000), 2018 (50.4 per 100,000) and 2019 (47.5 per 100,000), before falling steeply in 2020 to 13.5 per 100,000 and again in 2021 to a low of 2.1 per 100,000 (Figure 1a). Compared to the 2017 to 2019 mean rate (49.2 per 100,000), notification rates decreased by 72.6% (IRR, 0.27 [95% CI, 0.26–0.28]) in 2020 and 95.6% (IRR, 0.04 [95% CI, 0.04–0.05]) in 2021 (Table 1).

Table 1. Pertussis notification rates for 2020 and 2021 compared to the 2017 to 2019 mean annual rate, by jurisdiction and age group, Australia.

Jurisdiction and age group	2017 to 2019 mean	2020	2021	IRR 2020 vs. 2015-2019 (95% CI)	IRR 2021 vs. 2015-2019 (95% CI)
ACT					
0-4 years	76.6	14.4	0.0	0.18 (0.05 – 0.54)	< 0.001 (0.00 – 0.19)
5-14 years	156.2	21.6	1.8	0.14 (0.07 – 0.25)	0.01 (0.00 – 0.06)
15-24 years	58.3	19.0	0.0	0.32 (0.15 – 0.63)	< 0.001 (0.00 – 0.11)
25-69 years	44.2	8.3	2.6	0.19 (0.11 – 0.30)	0.06 (0.02 – 0.13)
≥ 70 years	43.9	2.5	7.1	0.06 (0.00 – 0.36)	0.16 (0.03 – 0.56)
Overall	63.5	11.8	2.5	0.19 (0.14 – 0.26)	0.04 (0.02– 0.07)
NSW					
0-4 years	179.0	43.4	1.7	0.24 (0.21 – 0.28)	0.01 (0.00 – 0.02)
5-14 years	265.3	47.0	0.5	0.18 (0.16 – 0.20)	< 0.001 (0.00 – 0.00)
15-24 years	53.5	13.9	0.4	0.26 (0.21 – 0.31)	0.01 (0.00 – 0.02)
25–69 years	37.5	9.6	0.4	0.26 (0.23 – 0.28)	0.01 (0.01 – 0.02)
≥ 70 years	25.5	5.6	0.4	0.22 (0.16 – 0.29)	0.02 (0.00 – 0.04)
Overall	74.9	16.2	0.5	0.22 (0.20 – 0.23)	0.01 (0.00 – 0.01)
NT					
0-4 years	75.7	5.6	5.7	0.07 (0.00 – 0.49)	0.08 (0.00 – 0.50)
5-14 years	47.9	22.9	0.0	0.47 (0.17 – 1.14)	<0.001 (0.00 – 0.24)
15-24 years	20.9	6.1	0.0	0.29 (0.03 – 1.53)	<0.001 (0.00 – 0.72)
25-69 years	21.0	2.6	2.0	0.13 (0.03 – 0.35)	0.09 (0.02 – 0.30)
≥ 70 years	15.9	0.0	0.0	<0.001 (0.00 – 4.65)	<0.001 (0.00 – 4.36)
Overall	28.9	6.1	1.6	0.21 (0.11 – 0.37)	0.06 (0.02 – 0.15)
Qld					
0-4 years	59.2	6.2	5.3	0.10 (0.06 – 0.17)	0.09 (0.05 – 0.15)
5-14 years	114.1	25.7	4.9	0.23 (0.19 – 0.27)	0.04 (0.03 – 0.06)

Table 1. continued

Jurisdiction and age group	2017 to 2019 mean	2020	2021	IRR 2020 vs. 2015-2019 (95% CI)	IRR 2021 vs. 2015-2019 (95% CI)
15-24 years	22.8	11.1	1.7	0.49 (0.36 – 0.65)	0.07 (0.04 – 0.14)
25-69 years	16.4	6.4	1.1	0.39 (0.33 – 0.46)	0.07 (0.04 – 0.09)
≥ 70 years	11.8	5.9	1.0	0.51 (0.32 – 0.78)	0.09 (0.03 – 0.20)
Overall	32.4	9.5	1.9	0.29 (0.26 – 0.32)	0.06 (0.05 – 0.07)
SA					
0-4 years	100.1	18.3	5.1	0.18 (0.10 – 0.30)	0.05 (0.02 – 0.12)
5-14 years	159.9	21.1	0.5	0.13 (0.10 – 0.18)	<0.001 (0.00 – 0.02)
15-24years	40.5	21.6	0.5	0.53 (0.37 – 0.77)	0.01 (0.00 – 0.07)
25-69 years	33.4	15.8	1.7	0.47 (0.39 – 0.57)	0.05 (0.03 – 0.08)
≥ 70 years	27.2	6.6	3.2	0.25 (0.13 – 0.43)	0.12 (0.05 – 0.25)
Overall	52.6	16.2	1.8	0.31 (0.27 – 0.35)	0.03 (0.02 – 0.05)
Tas					
0-4 years	118.0	40.5	0.0	0.34 (0.16 – 0.68)	<0.001 (0.00 – 0.11)
5-14 years	255.0	28.6	0.0	0.11 (0.07 – 0.18)	<0.001 (0.00 – 0.02)
15-24 years	51.9	1.6	0.0	0.03 (0.00 – 0.18)	<0.001 (0.00 – 0.12)
25-69 years	30.7	9.5	1.5	0.31 (0.20 – 0.46)	0.05 (0.02 – 0.12)
≥ 70 years	14.4	2.6	1.2	0.18 (0.02 – 0.86)	0.09 (0.00 – 0.63)
Overall	64.3	12.0	1.1	0.19 (0.14 – 0.24)	0.02 (0.01 – 0.04)
Vic					
0-4 years	35.3	25.6	3.9	0.72 (0.56 – 0.94)	0.11 (0.06 – 0.19)
5-14 years	64.2	29.2	1.7	0.45 (0.39 – 0.53)	0.03 (0.01 – 0.05)
15-24 years	19.2	15.1	4.6	0.79 (0.62 – 1.00)	0.24 (0.16 – 0.34)
25-69 years	25.9	13.9	5.7	0.54 (0.48 – 0.60)	0.22 (0.19 – 0.25)
≥ 70 years	28.5	14.1	3.7	0.50 (0.39 – 0.64)	0.13 (0.08 – 0.19)
Overall	30.3	16.4	4.7	0.54 (0.50 – 0.58)	0.15 (0.14 – 0.17)
WA					
0-4 years	86.4	5.8	0.0	0.07 (0.03 – 0.13)	<0.001 (0.00 – 0.03)
5-14 years	84.4	7.6	0.3	0.09 (0.06 – 0.14)	<0.001 (0.00 – 0.02)
15-24 years	31.3	4.3	0.6	0.14 (0.07 – 0.24)	0.02 (0.00 – 0.07)
25-69 years	32.0	3.9	2.3	0.12 (0.09 – 0.16)	0.07 (0.05 – 0.10)
≥ 70 years	38.9	4.2	2.3	0.11 (0.05 – 0.20)	0.06 (0.02 – 0.13)
Overall	43.3	4.7	1.8	0.11 (0.09 – 0.13)	0.04 (0.03 – 0.05)
Australia					
0-4 years	98.3	24.5	3.0	0.25 (0.22 – 0.28)	0.03 (0.02 – 0.04)
5-14 years	152.1	30.9	1.7	0.20 (0.18 – 0.22)	0.01 (0.01 – 0.01)
15-24 years	38.4	13.0	1.7	0.37 (0.33 – 0.42)	0.05 (0.04 – 0.07)
25-69 years	29.3	9.8	2.3	0.34 (0.32 – 0.36)	0.08 (0.07 – 0.09)
≥ 70 years	24.9	7.6	1.9	0.31 (0.26 – 0.36)	0.08 (0.06 – 0.10)
Overall	49.2	13.5	2.1	0.27 (0.26 – 0.28)	0.04 (0.04 – 0.05)

3.2.2 By jurisdiction

Between 2017 and 2019, New South Wales and Tasmania had the highest mean annual notification rates of (74.9 per 100,000 and 64.3 per 100,000, respectively), followed closely by the Australian Capital Territory (63.5 per 100,000). The lowest mean annual notification rates were observed in the Northern Territory and Victoria (28.9 per 100,000 and 30.0 per 100,000, respectively), followed closely by Queensland (32.4 per 100,000) and then Western Australia (43.3 per 100,000).

During the pandemic period, all jurisdictions saw a substantial and sustained decrease in pertussis notifications (Table 1). In 2020, the largest all-age decrease in pertussis notifications was observed in Western Australia (89.1%, 4.7 per 100,000 in 2020 compared to the mean of 43.3 per 100,000 between 2017 and 2019) (IRR, 0.11 [95% CI, 0.09–0.13]), which had the lowest overall annual notification rate in 2020. The second largest decrease in all-age pertussis notifications was observed in Tasmania (81.4%, 12.0 per 100,000 in 2020 compared to the mean of 64.3 per 100,000 between 2017 and 2019) (IRR, 0.19 [95% CI, 0.14–0.24]), followed by the Australian Capital Territory (80.8%, 2.5 per 100,000 in 2020 compared to the mean of 63.5 per 100,000 between 2017 and 2019) (IRR, 0.19 [95% CI, 0.14–0.26]). The smallest decrease in pertussis notifications was seen in Victoria (45.8 %, 16.4 per 100,000 in 2020 compared to the mean of 30.3 per 100,000 between 2017 and 2019) (IRR, 0.54 [95% CI, 0.50–0.58]), which had the highest overall annual notification rate in 2020.

In 2021, all-age pertussis notifications decreased further and were 90% lower than the baseline period in seven out of eight jurisdictions: New South Wales (99.3%) (IRR, 0.01 [95% CI, 0.00–0.01]); Tasmania (98.3%) (IRR, 0.02 [95% CI, 0.01–0.04]); South Australia (96.6%) (IRR, 0.03 [95% CI, 0.02–0.05]); the Australian Capital Territory (96.0%) (IRR, 0.04 [95% CI, 0.02–0.07]); Western Australia (95.9%) (IRR, 0.04 [95% CI, 0.03–0.05]); Queensland (94.2%) (IRR, 0.06 [95% CI, 0.05–0.07]); and the Northern Territory (94.3%) (IRR, 0.06 [95% CI, 0.02–0.15]). Victoria had the smallest decrease in notifications (84.6%) (IRR, 0.15 [95% CI, 0.14–0.17]).

In 2021, New South Wales and Tasmania had the lowest annual pertussis notification rates of 0.5 per 100,000 and 1.1 per 100,000, respectively. Victoria had the highest annual notification rate of 4.7 per 100,000, respectively.

3.2.3 By age group

National pertussis notification rates by 5-year age group for 2020 and 2021 compared to the 2017 to 2019 mean rate are shown in Figure A2 in Appendix A. Between 2017 and 2019, the highest age-specific mean annual notification rates in Australia were seen in children aged 5-9 years (165.7 per 100,000) and 10-14 years (137.7 per 100,000), followed by children aged 0-4 years (98.3 per 100,000). During 2020 and 2021, national notification rates decreased substantially across all age groups compared to their 2017 to 2019 mean rates.

Age-stratified analysis of national pertussis notifications showed that notification rates decreased substantially across all age groups (0-4 years; 5-14 years; 15-24 years; 25-69 years; and 70 years and over) in 2020 and 2021, when compared to their 2017 to 2019 national mean rates (Table 1). In 2020 and 2021, the largest rate decrease, 79.7% (IRR, 0.20 [95% CI, 0.18–0.22]) and 98.8% (IRR, 0.01 [95% CI, 0.01–0.01]), respectively, was observed in children aged 5-14 years (30.9 per 100,000 in 2020 and 1.7 per 100,000 in 2021, compared to a mean rate of 152.1 per 100,000 between 2017 and 2019). In 2021, rates across all age-groups decreased by over 90.0%, compared to the 2017 to 2019 period.

Age-stratified analyses of state and territory pertussis notifications showed that the Australian Capital Territory, New South Wales, Queensland, South Australia, Tasmania, and Western Australia all had significant decreases in pertussis notifications across all age groups during both pandemic years (2020 and 2021) when compared to the 2017 to 2019 mean (Table 1). In 2021, all jurisdictions except the Northern Territory had a significant decrease in notifications across all age groups ranging from 76.2% to 100%. In the Northern Territory there was a significant decrease across all age groups except older adults, aged 70 years and over (0.0 per 100,000 in 2021 compared to a mean of 15.9 per 100,000 between 2017 and 2019) (IRR, <0.001 [95% CI, 0.00-4.36]).

Among children aged 0-4 years, pertussis notification rates were significantly lower than the pre-pandemic period across all jurisdictions during each pandemic year. In Victoria, rates in 2020 and 2021 were 27.6% (IRR, 0.72 [95% CI, 0.56–0.94]) and 89.0% (IRR, 0.11 [95% CI 0.06–0.19]) lower, respectively, than the 2017 to 2019 pre-pandemic mean rate. In New South Wales, rates in 2020 and 2021 were 75.8% (IRR, 0.24 [95% CI, 0.21–0.28]) and 99.1% (IRR, 0.01 [95% CI, 0.00–0.02]) lower, respectively, than the pre-pandemic mean rate. In Tasmania, rates in 2020 and 2021 were 65.6% (IRR, 0.34 [95% CI 0.16–0.68]) and 100% (IRR, <0.001 [95% CI, 0.00–0.11]) lower, respectively, than the pre-pandemic mean rate. In Queensland, rates in 2020 and 2021 were 89.6% (IRR, 0.10 [95% CI, 0.06–0.17]) and 91.1% (IRR, 0.09 [95% CI, 0.05–0.15]) lower, respectively, than the pre-pandemic mean rate. In Western Australia and the Northern Territory, notifications among children aged 0-4 years had the largest decrease in 2020, with rates 93.3% (IRR, 0.07 [95% CI, 0.03–0.13]) and 92.5% (IRR, 0.07 [95% CI, 0.00–0.49]) lower, respectively, than the pre-pandemic mean rate. In 2020, the Northern Territory had the lowest overall annual pertussis notification rate among children aged 0-4 years (5.6 per 100,000), followed closely by Western Australia (5.8 per 100,000). In 2021, rates in Western Australia and the Northern Territory were 100% (IRR, <0.001 [95% CI, 0.00–0.03]) and 92.4% (IRR, 0.08 [95% CI, 0.00–0.05]) lower, respectively, than the pre-pandemic mean rate.

During 2021, the Australian Capital Territory, Tasmania, and Western Australia, each had no pertussis notifications among children aged 0-4 years. By contrast, the highest annual notification rate for this age group was seen in the Northern Territory (5.7 per 100,000 in 2021). When compared to crude and age group rates across all jurisdictions in 2021, children aged 0-4 years in the Northern Territory had the second highest notification rate (5.7 per 100,000), and adults aged 70 years and over in the Australian Capital Territory had the highest rate (7.1 per 100,000 in 2021).

Among children aged 5-14 years, the largest decrease in pertussis notification rates in 2020 was observed in Western Australia (90.8%) (IRR, 0.09 [95% CI, 0.06–0.14]), followed by Tasmania (88.8%) (IRR, 0.11 [95% CI, 0.07–0.18]), when compared to the 2017 to 2019 mean rate. The smallest decrease among children aged 5-14 years was seen in Victoria (54.8%) (IRR, 0.45 [95% CI, 0.39–0.53]). In 2021, the largest decrease among children aged

5-14 years was seen in Tasmania (100%) (IRR, <0.001 [95% CI, 0.00–0.02]), Western Australia (99.7%) (IRR, <0.001 [95% CI, 0.00–0.02]), and the Australian Capital Territory (98.9%) (IRR, 0.01 [95% CI, 0.00–0.06]), when compared to the 2017 to 2019 mean rate. The smallest decrease among this age group was seen in Queensland (95.6.%) (IRR, 0.04 [95% CI, 0.03–0.06]) and Victoria (97.3%) (IRR, 0.03 [95% CI, 0.01–0.05]).

3.2.4 Time trends by jurisdiction

Figure 2 shows jurisdictional trends in all-age monthly pertussis notifications in relation to state and territory public health measures comprising lockdown periods and mask mandates. For many jurisdictions, notifications were already below the 2017 to 2019 mean before the implementation of a national lockdown in March 2020. South Australia was the only state where notifications increased steadily in early 2020, peaking above mean levels in April before declining steeply. Toward the end of 2020 and throughout 2021, many jurisdictions had negligible numbers of pertussis notifications, which sat well below their 3-year mean.

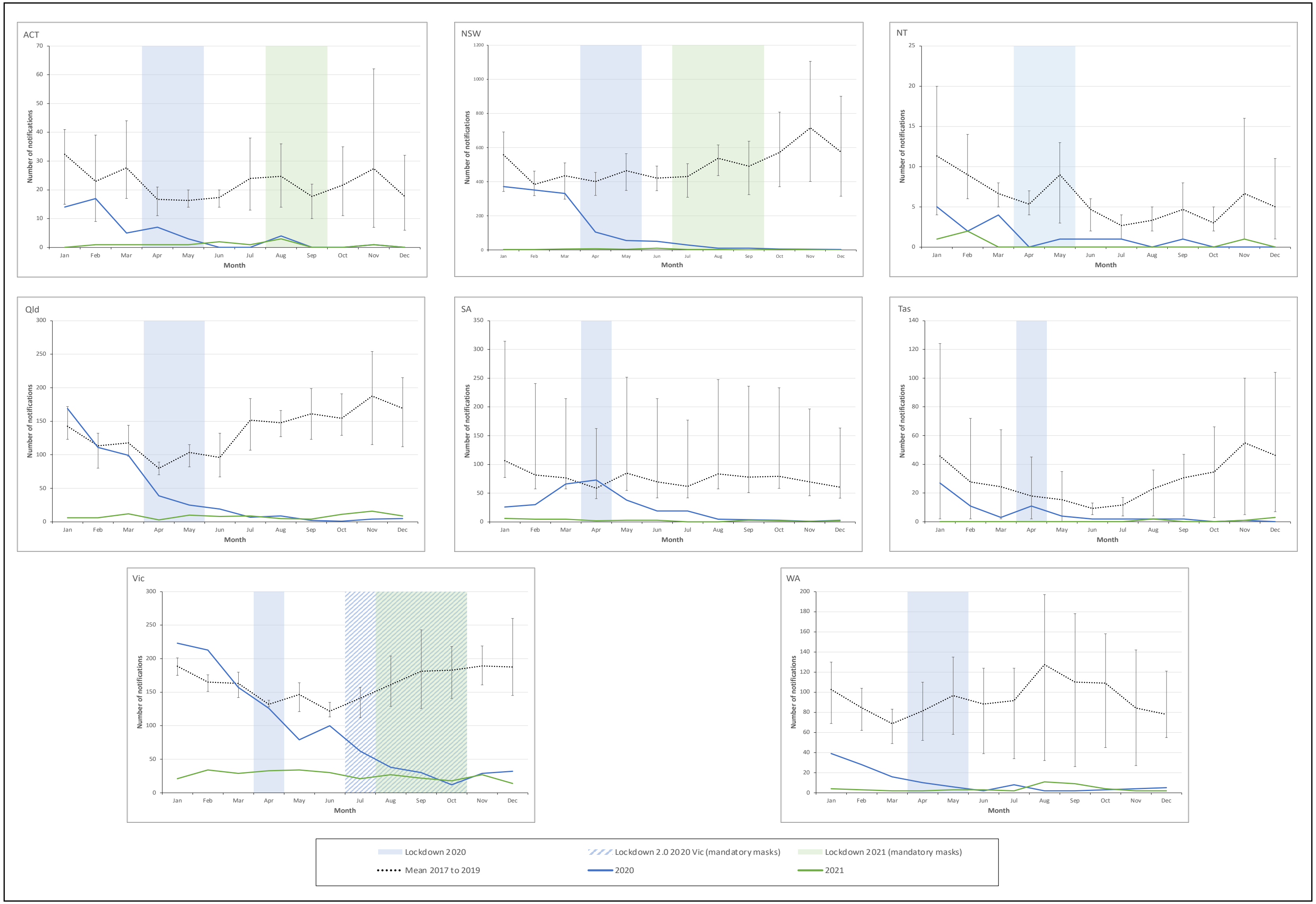

Figure 2. Australian state and territory pertussis notifications for 2020 and 2021 and the monthly mean for 2017 to 2019 with maxima and minima as error bars, showing lockdown periods and mask mandates (lockdown periods less than 1 month are not presented).

3.3 Invasive pneumococcal disease

3.3.1 Australia

Between 2015 and 2021, a total of 11,814 IPD notifications were recorded nationally. During this period all-age annual notification rates gradually increased from 6.3 per 100,000 in 2015 to 8.4 per 100,000 in 2019, before declining by almost 50% in 2020 (4.3 per 100,00) and rising marginally in 2021 (5.3 per 100,000) (Figure 1b). Compared to the 2015 to 2019 mean rate (7.6 per 100,000), national notification rates decreased by 42.8% in 2020 (IRR, 0.57 [95% CI, 0.53–0.62]) and 31.6% in 2021 (IRR, 0.68 [95% CI, 0.64–0.73]) (Table 2).

Table 2. Invasive pneumococcal disease notification rates for 2020 and 2021 compared to the 2015 to 2019 mean annual rate, by jurisdiction and age group, Australia.

Jurisdiction and age group	2015 to 2019 mean	2020	2021	IRR 2020 vs. 2015 to 2019 (95% CI)	IRR 2021 vs. 2015 to 2019 (95% CI)
ACT and NSW					
0-4 years	14.9	7.0	11.3	0.47 (0.31 – 0.71)	0.76 (0.53 – 1.08)
5-24 years	1.9	1.0	1.4	0.51 (0.29 – 0.89)	0.74 (0.45 – 1.22)
25-69 years	6.4	3.7	4.1	0.58 (0.48 – 0.70)	0.64 (0.53 – 0.77)
≥ 70 years	16.9	8.3	7.6	0.48 (0.38 – 0.61)	0.44 (0.34 – 0.55)
Overall	7.8	4.2	4.6	0.53 (0.47 – 0.61)	0.59 (0.52 – 0.67)
NT					
0-4 years	53.7	22.3	62.2	0.42 (0.10 – 1.46)	1.18 (0.45 – 3.10)
5-24 years	12.3	10.3	11.8	0.88 (0.27 – 2.77)	1.01 (0.33 – 3.08)
25-69 years	22.1	19.9	16.6	0.90 (0.53 – 1.53)	0.75 (0.43 – 1.30)
≥ 70 years	25.5	14.6	13.9	0.62 (0.09 – 3.67)	0.58 (0.09 – 3.43)
Overall	22.8	17.9	19.1	0.79 (0.52 – 1.19)	0.84 (0.56 – 1.26)
Qld					
0-4 years	12.4	9.4	14.6	0.76 (0.45 – 1.26)	1.18 (0.75 – 1.86)
5-24 years	2.6	1.9	2.1	0.74 (0.43 – 1.27)	0.80 (0.47 – 1.36)
25-69 years	5.5	3.8	4.2	0.68 (0.53 – 0.87)	0.75 (0.59 – 0.96)
≥ 70 years	10.7	6.0	6.7	0.54 (0.37 – 0.78)	0.60 (0.42 – 0.85)
Overall	6.2	4.2	4.9	0.67 (0.56 – 0.80)	0.78 (0.65 – 0.92)
SA					
0-4 years	47.2	47.7	67.7	1.01 (0.66 – 1.54)	1.43 (0.97 – 2.12)
5-24 years	2.3	2.1	2.1	0.89 (0.32 – 2.43)	0.89 (0.32 – 2.45)
25-69 years	6.9	3.7	5.1	0.54 (0.35 – 0.82)	0.74 (0.50 – 1.07)
≥ 70 years	11.5	6.1	9.6	0.52 (0.29 – 0.92)	0.81 (0.49 – 1.34)
Overall	9.3	6.5	9.1	0.70 (0.54 – 0.89)	0.97 (0.78 – 1.22)

Table 2. continued

Jurisdiction and age group	2015 to 2019 mean	2020	2021	IRR 2020 vs. 2015 to 2019 (95% CI)	IRR 2021 vs. 2015 to 2019 (95% CI)
Tas					
0-4 years	12.0	10.1	23.8	0.76 (0.11 – 4.48)	1.78 (0.45 – 8.28)
5-24 years	1.9	0.0	0.8	0.00 (0.00 – 5.24)	0.50 (0.01 – 9.56)
25-69 years	7.9	1.8	5.8	0.23 (0.08 – 0.59)	0.73 (0.38 – 1.40)
≥ 70 years	14.3	4.5	9.5	0.31 (0.09 – 0.92)	0.66 (0.27 – 1.57)
Overall	8.5	2.6	7.0	0.31 (0.16 – 0.57)	0.84 (0.53 – 1.32)
Vic					
0-4 years	13.6	7.1	12.7	0.52 (0.32 – 0.84)	0.94 (0.62 – 1.41)
5-24 years	1.7	0.4	0.9	0.26 (0.10 – 0.62)	0.57 (0.28 – 1.13)
25-69 years	6.1	2.6	2.7	0.43 (0.33 – 0.54)	0.45 (0.35 – 0.57)
≥ 70 years	15.6	5.0	7.7	0.31 (0.22 – 0.43)	0.48 (0.36 – 0.63)
Overall	7.2	2.8	3.8	0.39 (0.33 – 0.46)	0.53 (0.45 – 0.61)
WA					
0-4 years	17.2	15.6	22.2	0.90 (0.52 – 1.57)	1.28 (0.77 – 2.15)
5-24 years	3.2	1.6	2.6	0.51 (0.22 – 1.10)	0.82 (0.41 – 1.63)
25-69 years	7.1	7.6	6.1	1.07 (0.82 – 1.39)	0.86 (0.65 – 1.14)
≥ 70 years	11.5	5.3	7.2	0.45 (0.25 – 0.77)	0.60 (0.37 – 0.98)
Overall	7.9	6.8	6.9	0.85 (0.69 – 1.05)	0.87 (0.71 – 1.07)
Australia					
0-4 years	16.8	11.3	18.0	0.67 (0.55 – 0.82)	1.07 (0.90 – 1.27)
5-24 years	2.3	1.3	1.7	0.56 (0.42 – 0.74)	0.76 (0.58 – 0.98)
25-69 years	6.5	4.0	4.2	0.61 (0.55 – 0.68)	0.65 (0.59 – 0.72)
≥ 70 years	21.0	9.3	10.9	0.44 (0.38 – 0.51)	0.52 (0.44 – 0.59)
Overall	7.6	4.3	5.2	0.57 (0.53 – 0.62)	0.68 (0.64 – 0.73)

3.3.2 By jurisdiction

Between 2015 and 2019, the Northern Territory had the highest mean all-age annual notification rate for IPD (22.8 per 100,000), followed by South Australia (9.3 per 100,000). The lowest mean annual notification rates were observed in Queensland and Victoria (6.2 per 100,000 and 7.2 per 100,000, respectively).

During the pandemic period, IPD notifications decreased across all jurisdictions compared to the 2015 to 2019 mean, however, there was notable variation between states and territories (Table 2). In 2020, the largest all-age decrease was observed in Tasmania (69.2%, 2.6 per 100,000 in 2020 compared to the mean of 8.5 per 100,000 between 2015 and 2019) (IRR, 0.31 [95% CI, 0.16–0.57]), followed closely by Victoria (61.2%, 2.8 per 100,000 in 2020 compared to the mean of 7.2 per 100,000 between 2015 and 2019) (IRR, 0.39 [95% CI, 0.33–0.46]). The smallest decrease, which was not significant, was observed in Western Australia (14.6%, 6.8 per 100,000 in 2020 compared to the mean of 7.9 per 100,000 in 2015-2019) (IRR, 0.85 [95% CI, 0.69–1.05]).

In 2021, Victoria had the largest decrease in all-age IPD notifications, relative to 2015 to 2019 period, which fell by 47.5% (IRR, 0.53 [95% CI 0.45–0.61]) from 7.2 per 100,000 between 2015 to 2019 to the lowest overall annual notification rate of 3.8 per 100,000. South Australia had the smallest decrease which was not significant (2.7%, 9.1 per 100,000 in 2021 compared to the mean of 9.3 per 100,000 in 2015-2019) (IRR, 0.97 [95% CI, 0.79–1.22]).

The Northern Territory and Western Australia experienced smaller decreases in all-age IPD notifications than other jurisdictions and the IRRs were not statistically significant {Northern Territory (IRR in 2020, 0.79 [95% CI, 0.52–1.19]; IRR in 2021, 0.84 [95% CI, 0.56–1.26]) Western Australia (IRR in 2020, 0.85 [95% CI, 0.69–1.05]; IRR in 2021, 0.87 [95% CI, 0.71–1.07])}. Notification rates in the Northern Territory were the highest for any jurisdiction in both 2020 (17.9 per 100,000) and 2021 (19.1 per 100,000).

3.3.3 By age group

National IPD notification rates by 5-year age group for 2020 and 2021 compared to the 2015 to 2019 mean rate are shown in Figure A3 in Appendix A. Between 2015 and 2019, age-specific mean annual notification rates in Australia were highest in older adults with the highest rates seen among individuals aged 85 years and over (36.7 per 100,000), 80-84 years (23.0 per 100,000) and 65-79 years (18.4 per 100,000), followed by children aged 0-4 years (16.8 per 100,000). In 2020 and 2021, IPD annual notification rates were lower than the 2015 to 2019 mean rate across all age groups, except for children aged 0-4 years where the rate increased marginally in 2021 (18.0 per 100,000 in 2021 compared to the 2015 to 2019 mean of 16.8 per 100,000).

Age-stratified analysis of national IPD notifications showed that notification rates decreased across all age groups (0-4 years; 5-24 years; 25-69 years; and 70 years and over) in 2020, when compared to their 2015 to 2019 national mean rates (Table 2). In 2020, the largest rate decrease was seen among adults aged 70 years and over (56.0%, 9.3 per 100,000 compared to a mean rate of 21.0 per 100,000 between 2015 and 2019) (IRR, 0.44 [95% CI, 0.38–0.51]), followed by those aged 5-24 years (44.4%, 1.3 per 100,000 compared to a mean rate of 2.3 per 100,000 between 2015 to 2019) (IRR, 0.56 [95% CI 0.42–0.74]).

In 2021, national IPD notification rates decreased across all age groups, except for children aged 0-4 years, among whom notification rates increased by 7.1% compared to the 2015 to 2019 period (18.0 per 100,000 compared to a mean rate of 16.8 per 100,000 between 2015 and 2019) (IRR, 1.07 [95% CI, 0.90–1.27]). In 2021, the largest IPD rate decrease was seen among adults aged 70 years and over (48.3%, 10.9 per 100,000 compared to a mean rate of 6.5 per 100,000 between 2015 and 2019) (IRR, 0.52 [95% CI, 0.44–0.59]), followed by adults aged 25-69 years (35.0%, 4.2 per 100,000 compared to a mean rate of 6.5 per 100,000 between 2015 to 2019) (IRR, 0.65 [95% CI, 0.59–0.72]). Among those aged 5-24 years, IPD notification rates decreased by 24.3% in 2021 (1.7 per 100,000 compared to the 2015 to 2019 mean rate of 2.3 per 100,000) (IRR, 0.76 [95% CI, 0.58–0.98]).

Age stratified analysis of state and territory IPD notifications showed that compared to the 2015 to 2019 mean, the largest decrease in notifications occurred in 2020 among those aged 25-69 years (76.6%) (IRR, 0.23 [95% CI, 0.08–0.59]) residing in Tasmania, and 5-24 years (73.9%) (IRR, 0.26 [95% CI, 0.10–0.62]) residing in Victoria (Table 2). In 2021, the largest decrease was observed in the Australian Capital Territory and New South Wales, where IPD notifications deceased by 56.4% (IRR, 0.44 [95% CI, 0.34–0.55]) among adults aged 70 years and over.

Among children aged 0-4 years, IPD notifications decreased significantly during 2020 compared to the 2015 to 2019 mean in the Australian Capital Territory and New South Wales (52.8%) (IRR, 0.47 [95% CI, 0.31–0.71]), and Victoria (47.6%) (IRR, 0.52 [95% CI, 0.32–0.84]). In 2021, while there was no statistically significant change in notifications for this age group in any state or territory when compared to the pre-pandemic period, IPD notifications were higher than the 2015 to 2019 mean in all jurisdictions except for Victoria, and the Australian Capital Territory and New South Wales, where they remained below their respective means.

The Northern Territory was the only jurisdiction that did not have a significant decrease in IPD notifications among any age group in 2020 and 2021 when compared to the 2015 to 2019 mean rate (Table 2). In Western Australia, the only significant change was among those aged 70 years and over, with rates falling by 55.2% (IRR, 0.45 [95% CI, 0.25–0.77]) and 39.9% (IRR, 0.60 [95% CI, 0.37–0.98]), respectively, in 2020 and 2021, compared to the 2015 to 2019 mean. Queensland also had significant declines in IPD notifications across both pandemic years compared to the 5-year mean, but only amongst adults aged 25-69 which decreased by 32.1% in 2020 (IRR, 0.68 [95% CI, 0.53–0.87]) and 24.8% in 2021 (IRR, 0.75 [95% CI, 0.59–0.96]), and among adults 70 years and over which decreased by 45.8% in 2020 (IRR, 0.54, [95% CI, 0.37–0.78]) and 40.0% in 2021 (IRR, 0.60 [95% CI, 0.42–0.85]).

3.3.4 Time trends by jurisdiction

Figure 3 shows jurisdictional trends in all-age monthly IPD notifications, in relation to state and territory public health measures comprising lockdown periods and mask mandates.
In the Australian Capital Territory and New South Wales, IPD notifications fell well below the 2015 to 2019 annual mean rate during both pandemic years, coinciding with the national lockdown in late-March 2020 and preceding the lockdown in August 2021. When lockdowns were lifted, notifications subsequently increased, but remained below the mean. For example, after the 2020 national lockdown was lifted in mid-May, IPD notifications in the Australian Capital Territory and New South Wales increased by 292.9% between May and July. By contrast, in Western Australia, IPD notifications showed minimal deviation from the 5-year mean, particularly during 2021.

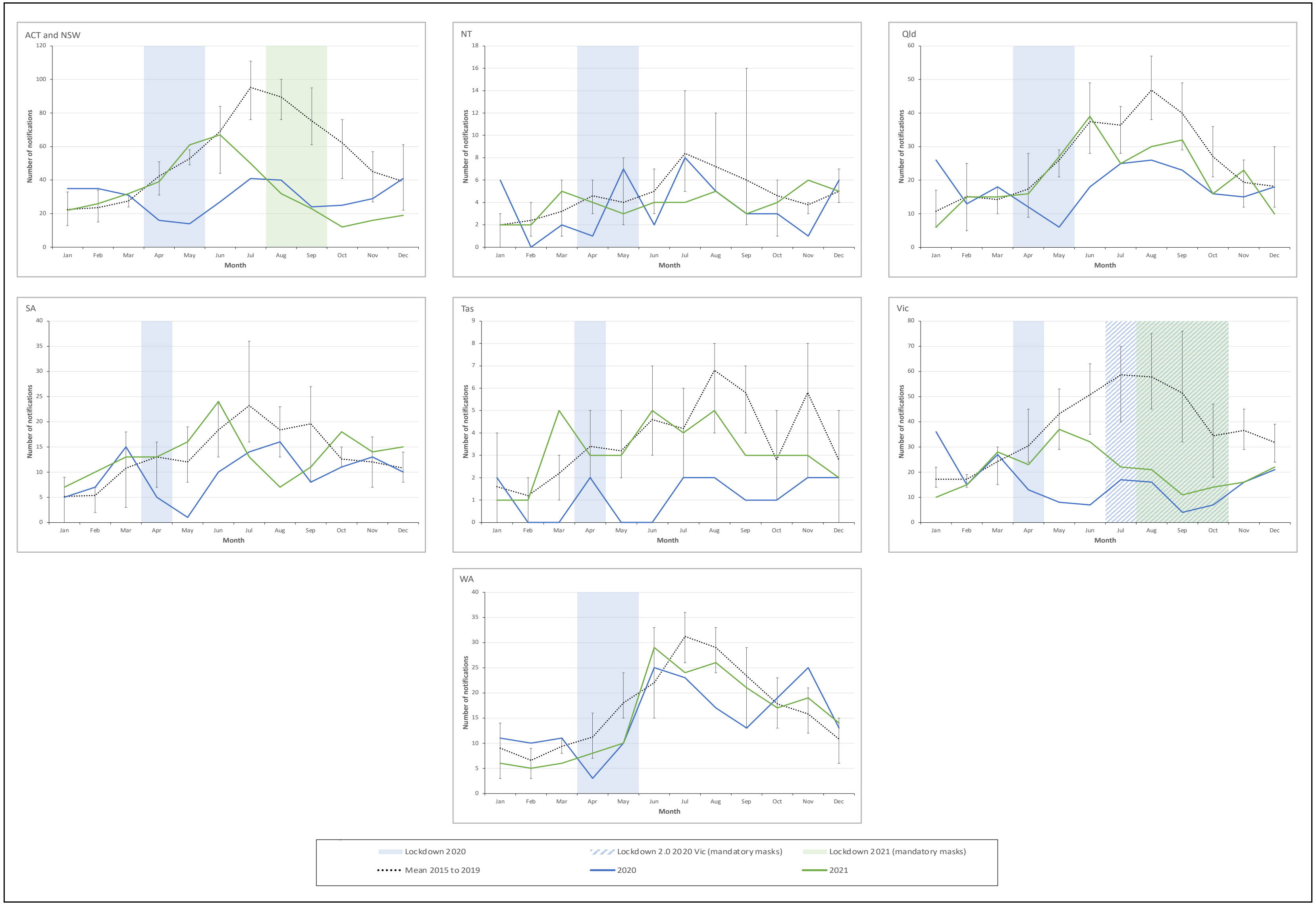

Figure 3. Australian state and territory invasive pneumococcal disease notifications for 2020 and 2021 and the monthly mean for 2015 to 2019 with maxima and minima as error bars, showing lockdown periods and mask mandates (lockdown periods less than 1 month are not presented)

3.4 Invasive meningococcal disease

3.4.1 Australia

Between 2015 and 2021, a total of 1,464 IMD notifications were recorded nationally. During this period all-age annual notification rates increased from 0.8 per 100,000 in 2015 to a peak of 1.5 per 100,000 in 2017, before decreasing steadily to 0.8 per 100,000 in 2019, 0.4 per 100,000 in 2020, to a low of 0.3 per 100,000 in 2021 (Figure 1c). Compared to the 4-year mean rate (2015 to 2019, excluding 2017) of 0.9 per 100,000, national notification rates decreased by 62.5% in 2020 (IRR, 0.38 [95% CI, 0.29–0.48]) and 69.1% in 2021 (IRR, 0.31 [95% CI, 0.23–0.40]) (Table 3).

Table 3. Invasive meningococcal disease notification rates for 2020 and 2021 compared to the 4-year mean annual rate (2015 to 2019, excluding 2017), by jurisdiction, Australia.

Jurisdiction	2015 to 2019 mean, excluding 2017	2020	2021	IRR 2020 vs. 2015-2019, excluding 2017 (95% CI)	IRR 2021 vs. 2015-2019, excluding 2017 (95% CI)
ACT and NSW	0.8	0.3	0.3	0.35 (0.21 – 0.57)	0.35 (0.21 – 0.57)
NT	2.0	0.8	0.8	0.40 (0.04 – 2.44)	0.40 (0.04 – 2.44)
Qld	0.9	0.5	0.3	0.57 (0.34 – 0.94)	0.29 (0.15 – 0.55)
SA	1.7	0.3	0.7	0.17 (0.05 – 0.44)	0.40 (0.19 – 0.81)
Tas	1.6	0.6	0.4	0.32 (0.06 – 1.29)	0.22 (0.02 – 1.04)
Vic	0.9	0.3	0.2	0.32 (0.18 – 0.55)	0.19 (0.09 – 0.36)
WA	1.0	0.4	0.4	0.41 (0.18 – 0.86)	0.37 (0.16 – 0.79)
Australia	0.9	0.4	0.3	0.38 (0.29 – 0.48)	0.31 (0.23 – 0.40)

3.4.2 By jurisdiction

Between 2015 and 2019 (excluding 2017), the Northern Territory had the highest mean all-age annual notification rate for IMD (2.0 per 100,000), followed by South Australia (1.7 per 100,000). The lowest mean annual notification rates were observed in the Australia Capital Territory (0.8 per 100,000), followed by Queensland and Victoria (0.9 per 100,000, respectively).

During the pandemic period, IMD notifications decreased across all jurisdictions compared to the 4-year mean rate (2015 to 2019, excluding 2017) (Table 3). In 2020, South Australia had the largest decrease in all-age IMD notification rates (83.2%, 0.3 per 100,000 compared to the 4-year mean of 1.7 per 100,000) (IRR, 0.17 [95% CI, 0.05–0.44]), followed by Victoria (68.0%, 0.3 per 100,000 compared to the 4-year mean of 0.9 per 100,000) (IRR, 0.32 [95% CI, 0.18–0.55]). Both jurisdictions had the lowest annual IMD notification rate in 2020 (0.3 per 100,000). In 2020, the smallest decrease in all-age IMD notification rates was observed in Queensland (42.8%, 0.5 per 100,000 in 2020 compared to the 4-year mean of 1.7 per 100,000) (IRR, 0.57 [95% CI, 0.34–0.94]), followed by Western Australia (59.1%, 0.4 per 100,000 compared to the 4-year mean of 1.0 per 100,000) (IRR, 0.41 [95% CI, 0.18–0.86]).

In 2021, Victoria had the largest decrease in IMD notifications of all states and territories (81.4%) (IRR, 0.19 [95% CI, 0.09–0.36]) when compared to the 4-year mean (0.9 per 100,000) to reach the lowest overall rate in 2021 of 0.2 per 100,000. Furthermore, South Australia had the smallest decrease in IMD notifications, which compared to the 4-year mean, declined by 59.7% (IRR, 0.40 [95% CI, 0.19–0.81]) in 2021 to 0.7 per 100,000 but was over two times higher than the 2020 notification rate (0.3 per 100,000).

The Northern Territory and Tasmania experienced smaller decreases in IMD notifications than other jurisdictions and the IRRs were not statistically significant {Northern Territory (IRR in 2020, 0.40 [95% CI, 0.04–2.44]; IRR in 2021, 0.40 [95% CI, 0.04–2.44]) Tasmania (IRR in 2020, 0.32 [95% CI, 0.06–1.29]; IRR in 2021, 0.22 [95% CI, 0.02–1.04])}. Between 2015 and 2019 (excluding 2017), the Northern Territory had the highest mean all-age IMD annual notification rate (2.0 per 100,000), followed by South Australia (1.7 per 100,000). In the Northern Territory, IMD notifications remained the highest in both 2020 and 2021 (0.8 per 100,000, respectively) at levels two times that of the national rate (0.4 per 100,000 in 2020, and 0.3 per 100,000 in 2021).

3.4.3 By age group

National IMD notification rates by 5-year age group for 2020 and 2021 compared to the 2015 to 2019 (excluding 2017) mean rate are shown in Figure A4 in Appendix A. Between (2015 to 2019, excluding 2017), the highest age-specific mean IMD annual notification rates in Australia were seen in children aged 0-4 years (3.6 per 100,000), followed by adolescents aged 15-19 years (2.3 per 100,000), and adults aged 80-84 years and 85 years and over (1.4 per 100,000).

In 2020, IMD annual notification rates were lower than the 4-year mean rate across all age groups, except for children aged 10-14 years. In 2021, IMD annual notification rates were lower than the 4-year mean rate across all age groups, except for children aged 10-14 years and adults aged 40-44 years. In 2020 and 2021, rates among children aged 10-14 were the same as the 4-year mean rate (0.2 per 100,000). In 2021, rates among adults aged 40-44 years were the same as the 4-year mean rate (0.2 per 100,000).

In 2020, largest decrease in IMD notification rates was observed among adults aged 60-64 years followed by adults aged 80-84 years, which compared to the 4-year mean rate, declined by 88.9% (0.1 per 100,000 compared to the mean rate of 0.9 per 100,000) and 84.6 % (0.2 per 100,000 compared to the mean rate of 1.3 per 100,000), respectively. In 2021, the largest decrease in IMD notification rates was observed among adults aged 75-79 years followed by adults aged 70-74 years, which compared to the mean rate, declined by 100% (0.0 per 100, 000 compared to the mean rate of 1.0 per 100,000) and 90.9% (0.1 per 100,000 compared to the mean rate of 1.1 per 100,000), respectively.

In 2020 and 2021, IMD notification rates remained the highest among children aged 0-4 years (1.8 per 100,000 in 2020 and 1.1 per 100,000 in 2021), followed by adolescents aged 15-19 years (0.7 per 100,000 in 2020 and 0.8 per 100,000 in 2021).

3.4.4 Time trends by jurisdiction

Figure 4 shows jurisdictional trends in all-age monthly IMD notifications, in relation to state and territory public health measures comprising lockdown periods and mask mandates. In the Australian Capital Territory and New South Wales, between the months of July and October IMD notifications in 2020 and 2021 plateaued well below the 4-year mean, without the usual seasonal spring peak. A similar pattern was also observed in South Australia, Victoria, and Western Australia.

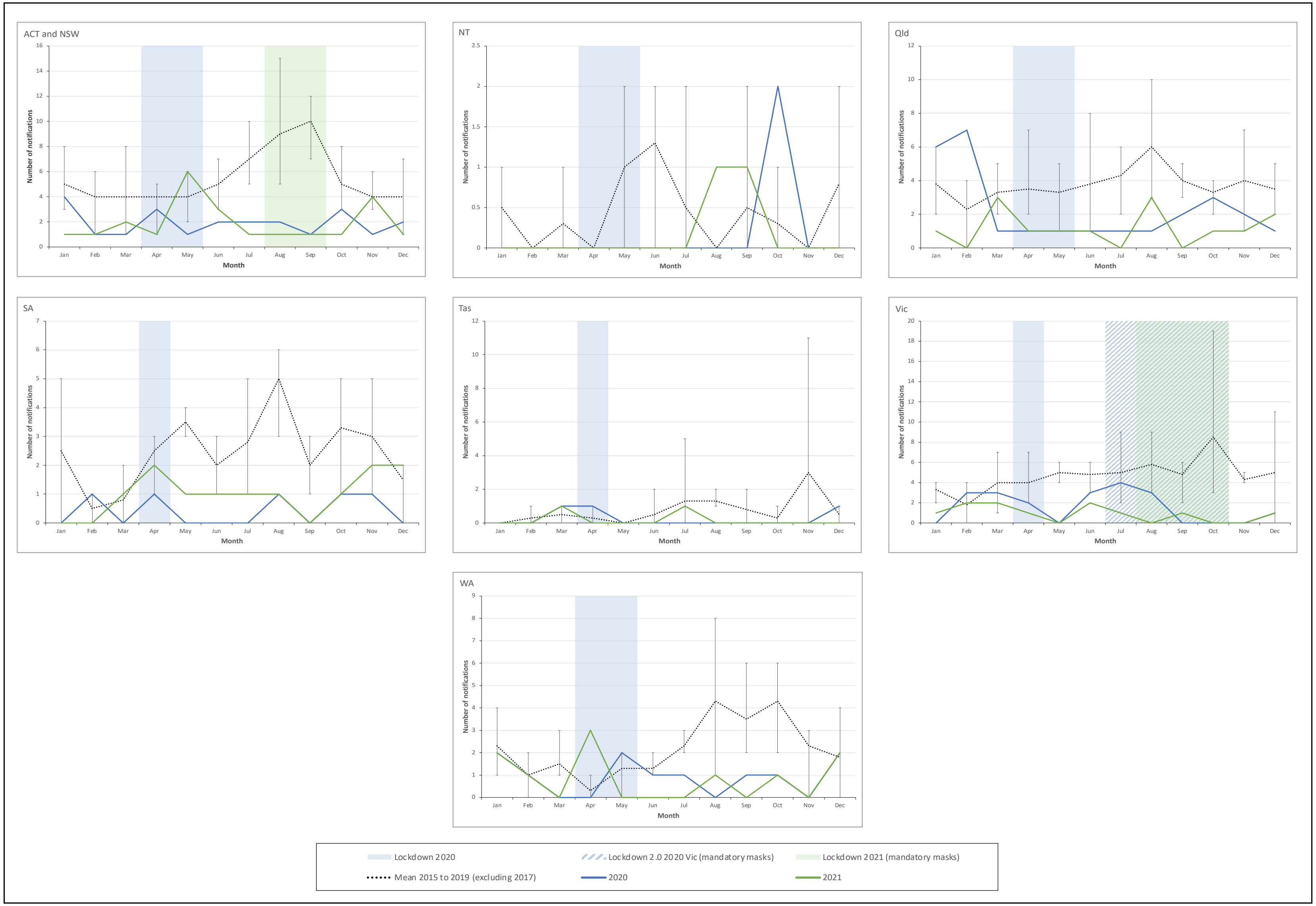

Figure 4. Australian state and territory invasive meningococcal disease notifications for 2020 and 2021 and the monthly mean for 2015 to 2019 (excluding 2017) with maxima and minima as error bars, showing lockdown periods and mask mandates (lockdown periods less than 1 month are not presented).

3.5 Sensitivity analysis

Sensitivity analysis for pertussis (Table A2, Appendix B) showed that, when the pre-pandemic comparison period included epidemic years (2015 and 2016), there was a greater decrease in all-age national pertussis notification rates in 2020 (6.5%) and 2021 (1.0%), when compared to the primary analysis. Except for adults aged 70 years and over, there was a greater decrease in national pertussis notification rates across all age groups in 2020 (4.9% to 7.1%) and 2021 (0% to 2.0%), when compared to the decrease observed in the primary analysis. For older adults aged 70 years and over, the decrease in national pertussis notifications was smaller in 2020 (34.9%) and 2021 (8.6%), compared to the primary analysis.

When the pertussis pre-pandemic comparison period included epidemic years, there was a greater decrease in all-age and age group notifications across all jurisdictions, except Tasmania, in 2020 (0.1% to 24.0%) and 2021 (0% to 6.9%), when compared to the decrease observed in the primary analysis. In Tasmania, the decrease in all-age and age-group pertussis notifications was smaller in 2020 (1.6% to 16.1%) and 2021 (0% to 2.7%) compared to the primary analysis, and no longer statistically significant among adults aged 70 years and over in 2020 (IRR, 0.22 [95% CI, 0.02–1.10]).

Sensitivity analysis for IMD (Table A3, Appendix B) showed that, when the year 2017 was included in the pre-pandemic comparison period, there was a greater decrease in all-age IMD national notification rates in 2020 (4.4%) and 2021 (3.6%), when compared to the decrease observed in the primary analysis. Furthermore, when 2017 was included in the pre-pandemic comparison period, there was a greater decrease in national IMD notification rates across all 5-year age groups in 2020 (0.5% to 37.8%) and 2021 (0.5% to 37.8%), when compared to the decrease observed in the primary analysis. In addition, there was a greater decrease in all-age IMD notification rates across all states and territories in 2020 (1.1% to 19.9%) and 2021 (2.5% to 20.0%), when compared to the decrease observed in primary analysis.

For IMD, the decrease seen in the sensitivity analysis was significantly larger in the Northern Territory such that, when 2017 was included in the pre-pandemic comparison period, there was a 20% greater decrease in IMD notification rates in both pandemic years, when compared to the decrease observed in the primary analysis. As a result, the decrease in all-age IMD notification rates in the Northern Territory became significant for both 2020 (IRR, 0.20 [95% CI, 0.02–0.94]) and 2021 (IRR, 0.20 [95% CI, 0.02–0.94]). In Tasmania, when 2017 was included in the pre-pandemic comparison period, there was a greater decrease in IMD notification rates in 2020 (3.3%) and 2021 (2.2%), when compared to the decrease observed in the primary analysis. As with the primary analysis, the rate decreases in Tasmania remained insignificant in 2020 (IRR, 0.29 [95% CI, 0.05–1.13]), however reached significance in 2021 (IRR, 0.19 [95% CI, 0.02–0.91]), which was not observed in the primary analysis (IRR, 0.22 [95% CI, 0.02–1.04]).

4. Discussion

This study showed significant decreases in pertussis, IPD, and IMD notifications following the implementation of COVID-19 targeted public health measures in Australia. For pertussis, national notifications declined markedly with all states and territories demonstrating a substantial and sustained decrease in notifications. From May 2020 onwards, following the initial COVID-19 national lockdown, all-age monthly pertussis notifications remained consistently well below the previous 3-year mean in all jurisdictions. In 2021, for seven out of eight states and territories all-age notification rates were over 90% lower than the pre-pandemic period. For IPD and IMD, the decrease in notifications showed considerable variation between states and territories with Victoria having the highest decrease in 2021 and second highest decrease in 2020. In the case of IPD, the decrease in notifications also varied considerably by age. Within jurisdictions, compared with the pre-pandemic period, significant declines in IPD were most observed among adults aged 25-69 years and 70 years and over than among younger age groups. For those aged 0-4 and 5-24 years, significant declines were only observed during 2020 in the Australian Capital Territory and New South Wales, and Victoria.

Following the decision by National Cabinet to implement a nationwide lockdown in early 2020,[81] all states and territories additionally and independently implemented a series of COVID-19 targeted NPIs. As these consisted of a wide array of measures that varied between jurisdictions in type, timing, and level of enforcement, it is not possible to establish which specific interventions had the greatest individual impact in reducing transmission of pertussis, IPD, and IMD. The differences in changes in notification rates between jurisdictions in this study suggest that there may have been differential impacts of certain public health measures (such as lockdowns compared to hard interjurisdictional border closures) in reducing the transmission of the studied infectious diseases within different states and territories in Australia.

Compared with the pre-pandemic period, in 2020, pertussis notification rates decreased nationally, in all jurisdictions, and across all age groups. There was a further and substantial decrease throughout 2021 in all-age and age group pertussis notifications, nationally, and in all jurisdictions. This sustained decrease is possibly due to the cumulative impact of successive NPIs causing lasting behavioural change throughout the pandemic period.

In 2020, the largest decreases in pertussis notifications occurred in Western Australia, Queensland, and the Northern Territory. Both Western Australia and Queensland implemented hard interjurisdictional border closures to all other jurisdictions and had shorter lockdown periods. Similarly, for 118 days in 2020, the Northern Territory had very stringent border restrictions and quarantine measures, also implementing a shorter lockdown period.[81, 87] Additionally, in 2020, all non-essential travel to the territories' 76 remote Indigenous communities was restricted under the *Biosecurity Act 2015*.[88, 89]

In 2020, Western Australia had the largest decline in all-age pertussis notifications in addition to the largest decrease in notifications among children aged 0-4 years and 5-14 years, when compared to the pre-pandemic period. The Northern Territory and Queensland had the second and third largest declines in pertussis notifications among young children aged 0-4 years. In 2020, Western Australia had the lowest all-age annual pertussis notification rate and the second lowest annual pertussis notification rate among children aged 0-4 years. Furthermore, in 2020, the Northern Territory had the second lowest all-age annual pertussis notification rate and the lowest annual pertussis notification rate among children aged 0-4 years. In addition, in 2020, Queensland had the third lowest all-age pertussis notification rate and the third lowest annual pertussis notification rate among children aged 0-4 years.

These states and territories also had low pertussis notification rates during the pre-pandemic period. Between 2017 and 2019, the Northern Territory had the lowest all-age pertussis mean annual notification rate. Queensland had the third lowest all-age pertussis mean annual notification rate and second lowest pertussis mean annual notification rate among children aged 0-4 years. Western Australia had the fourth lowest pertussis mean annual notification rate overall and for children aged 0-4 years. This suggests that early in the pandemic, for jurisdictions with low pre-pandemic disease rates, pertussis transmission may have been more impacted through preventing interstate importation of infection as opposed to preventing within jurisdiction circulation of infection.

In contrast, Victoria had the highest number of lockdown days and some of the strictest NPIs throughout the pandemic period. In 2020 and 2021, Victoria had the smallest decrease in all-age pertussis notifications and the smallest decrease in pertussis notifications among children aged 0-4 years and 5-14 years. Furthermore, in 2020 and 2021, Victoria had the highest all-age pertussis annual notification rate. However, between 2017 and 2019, Victoria had the second lowest all-age pertussis mean annual notification rate; the lowest pertussis mean annual notification rate among children aged 0-4 years; and the second lowest mean annual notification rate among children aged 5-14 years.

As pertussis is highly contagious through the respiratory route,[33] community transmission might have been less impacted by local-level disease containment measures in jurisdictions with low level background transmission, where imported infections seed into the community. In the case of Victoria, which has a high population density[90] and low background pertussis rates, strict internal containment measures in the absence of a hard border closure had less impaction on pertussis notifications.

For pertussis, we observed a substantial decrease in notifications across all age groups, nationally and in all jurisdictions. In 2020 and 2021, the largest declines in national notifications occurred among children aged 0-4 years and 5-14 years, which had the highest rates of pertussis notifications in the pre-pandemic period. The reduction in notifications among young children potentially has beneficial clinical implications, particularly for reduced pertussis morbidity and mortality among young infants aged less than 1 year who have the highest risk of hospitalisation due to pertussis infection.[45]

To date, there are very few Australian studies exploring the relationship between COVID-19 NPIs and pertussis notifications and of these none have looked at age-group data. However, regional studies in Central Queensland and Victoria, using the same NNDSS data, have shown consistent all-age pertussis notification rates to our study.[51, 52]

Overseas studies have also demonstrated a significant and sustained decrease in pertussis cases temporally associated with the introduction of COVID-19 NPIs among all age groups, including young children.[32, 33] In England, a national population based study found that compared to the preceding 5-year mean, national pertussis notifications in 2020/2021 decreased by 94% in children aged 1-4 years (IRR, 0.06 [95% CI, 0.02–0.15]), and more than 97% in children under 1 year of age (IRR, 0.02 [95% CI 0.00–0.06]), children aged 5-14 years (IRR, 0.01 [95% CI, 0.01–0.02]), and those aged 15 years and over (IRR, 0.02 [95% CI, 0.01–0.02]).[33] In France, time series analysis of laboratory surveillance data from two national outpatient laboratories between 2013 and 2020 showed that throughout 2020 pertussis cases decreased by more than 90% in children aged 6-17 years (IRR, 0.07 [95% CI, 0.03–0.20]) and adults aged 18 years and over (IRR, 0.06 [95% CI, 0.03–0.15]), and more than 75% among children aged 0-5 years (IRR, 0.22 [95% CI, 0.08–0.56]). For children under 1 year of age, data from a nationwide network of 41 hospitals showed that the number of pertussis hospitalisations decreased by 78% (IRR, 0.22 [95% CI 0.07–0.66]).[32]

Furthermore, Huh *et al* found that in The Republic of Korea children and adolescents were the only age groups to have a significant decline in pertussis notifications following the introduction COVID-19 NPIs.[18] In their study, during the first half of 2020 national pertussis notifications among children aged 0-6 years and 7-17 years decreased by 64% (p=0.01) and 79% (p=0.03), respectively, compared to the 2016 to 2019 mean.[18] However, among adults aged 18 years and over the decrease (42%) was not statistically significant (p=0.24). One possible explanation is that in The Republic of Korea, implementation of school closures and other public health measures impacted children more than adults.[18] It is worth noting this study was limited to 6-months early in the pandemic period and it has not been reported whether these age specific declines were sustained.

With regards to IPD and IMD, in 2020, when compared to the pre-pandemic period, Tasmania had the largest decrease in all-age IPD notification rates and South Australia had the largest decrease in all-age IMD notification rates. However, in 2021, both states had a sizable increase in notifications which more than doubled the rate of the previous year but remained below pre-pandemic levels. As South Australia also had a short circuit breaker lockdown at the end of 2020,[82] and the second highest IMD notification rates in the pre-pandemic period, it is possible this bounce back occurred in the wake of less stringent public health measures throughout 2021.

In 2020, Victoria had the second largest decrease in all-age notification rates for IPD and IMD. Furthermore, in 2021, Victoria had the largest decrease in notification rates for IPD and IMD, resulting in the lowest annual notification rate overall for each of these diseases. These sustained decreases are possibly due to the cumulative impact of significant behavioural change from stringent public health measures including long lockdown periods and mask mandates in 2020 and 2021.

In contrast, Western Australia had far fewer lockdown days instead implementing a hard border to the rest of the country for 223 days in 2020 and a strict 'controlled border' thereafter and throughout 2021. It also had minimal change in IPD notifications throughout the entire study period. Furthermore, in 2020, Western Australia and Queensland had the smallest decrease in IMD notification rates. Additionally, in 2020, the Northern Territory implemented stringent border restrictions and prohibited all non-essential travel into remote Indigenous communities. During 2020 and 2021, the Northern Territory had no significant decrease in IPD and IMD notification rates, compared to the pre-pandemic period.

These interjurisdictional variations in the change in IPD and IMD notification rates during the pandemic may be due to the implementation of NPIs which limited individual proximity within a jurisdiction. An extensive study by Breuggermann *et al*, examining international surveillance data of IPD and IMD from national reference laboratories across 26 countries, found that coinciding with the introduction of COVID-19 measures in each country, there was a substantial and sustained decline in IPD and IMD in early 2020 when compared to the same period in 2018 and 2019.[35] Furthermore, additional analysis of IPD found that the reductions in incidence were directly associated with the stringency of containment measures in addition to the corresponding reductions in movement of people within their community.[35, 91] Compared to expected time series trends for 2018 and 2019, IPD decreased by 68% at 4 weeks (IRR, 0.32 [95% CI, 0.27–0.37]) and 82% at 8 weeks (IRR, 0.18 [95% CI, 0.14–0.23]) following the week when significant reductions in population movements were observed.[35]

In Victoria, strict NPIs preventing movement of people within the community would have prevented circulation of pneumococcus and meningococcus within the state. Conversely, in Western Australia and Queensland, hard border closures prevented imported disease from entering the state. Similarly, in the Northern Territory, stringent border restrictions and internal travel bans also prevented imported disease from entering the state and remote communities. As invasive disease occurs via the spread of pneumococcus or meningococcus from its ecological niche, where it resides asymptomatically in the nasopharynx (nasal carriage),[92, 93] transmission is more likely to be influenced by measures which limit person to person contact i.e., measures within a jurisdiction or community, as opposed to measures aimed at preventing the arrival of imported disease. In the case of Western Australia and the Northern Territory, high background pneumococcus carriage rates, particularly among Indigenous children,[55, 94] and lack of NPIs targeted at preventing person to person contact and circulation within their own community, may account for the minimal change in IPD notifications observed during the pandemic period.

Pneumococcus carriage is likely higher in the Northern Territory due to there being a high proportion of Indigenous Australians living in remote communities, among whom higher rates of nasopharyngeal carriage have been observed (75.0%), compared to those living in a residential area (47.6%).[94] Additional risk factors within remote Indigenous communities relating to the social determinants of health such as poor living conditions, overcrowded housing, and high mobility increase the likelihood of invasive disease within this population.[95]

Furthermore, for the Northern Territory, high pre-pandemic IPD and IMD notification rates might also indicate higher rates of bacterial carriage within this population compared to other states and territories. Between 2015 and 2021, the Northern Territory consistently had the highest notification rates for IPD and between 2017 and 2021 it consistently had the highest notification rates for IMD. Compared to all other jurisdictions, the Northern Territory has historically had the highest rates of IPD,[49, 67] and some of the highest rates of IMD caused by MenB.[70]

In this study it was observed that the decrease in IPD and IMD varied by age. For IPD, compared to the pre-pandemic period, adults aged 70 years and over (one of the groups at particularly high risk for IPD)[67] had the largest decrease in national IPD notification rates in 2020 and 2021. Within jurisdictions the decrease in IPD was most observed in middle (25-69 years) and older adult (70 years and over) age groups than in younger age groups (0-4 years and 5-24 years). In Western Australia, adults aged 70 years and over were the only age group in this state that had a significant decrease in IPD notifications across both pandemic years. Similarly, for IMD, compared to the pre-pandemic period, the largest decrease in national notification rates was seen among adults aged 60-64 years in 2020, and 75-79 years in 2021. In Australia, adults aged 65 years and over have been shown to have the highest rates of IMD from MenW and MenY serogroups.[60]

Research by Subbarao *et al* examining national IMD surveillance data in England between April to August 2020, also found that when compared to the same period in 2019, the largest decline in IMD occurred in older adults, with those aged 65 years and over having an 86% reduction in IMD activity (IRR, 0.14 [95% CI, 0.06–0.32]).[39] However, compared to what was observed in this present study, where notification rates among children aged 10-14 years did not change during the pandemic period, Subbarao *et al* reported a considerable reduction in cases (80%) among children aged 5-14 years (IRR, 0.20 [95% CI 0.07–0.58]).

Other research examining national IPD laboratory surveillance data in England found a 30% decrease in IPD incidence among children aged less than 16 years (IRR, 0.71 [95% CI, 0.11 – 10.00]); adults aged 16-64 years (IRR, 0.65 [95% CI, 0.11 – 3.79]); and older adults 65-84 years (IRR, 0.72 [95% CI, 0.29 – 1.74]) and 85 years and over (IRR, 0.69 [95% CI, 0.42–1.76]) in 2019/2020 following COVID-19 lockdown measures, when compared to the 2018/2019 period.[37] However, the decreases observed were not significant. It is worth noting this study was limited to 6-months early in the pandemic period and it has not been reported whether these declines continued to be insignificant.

One possible explanation for why this study and some others observed a greater decrease in IPD and IMD among older age groups, is that through the instigation of NPIs such as lockdowns, adults (and older adults in particular) have been protected from exposure to pneumococcus or meningococcus by younger children.[37] Children are considered to have the highest rates of nasal carriage (ranging from 20-40% in healthy children).[93] As older adults are at increased risk of serious illness form COVID-19,[96] it is also possible that they and their family members (including young children who are potential carriers) deliberately avoided close contact, even when not strictly required, in order minimise the possibility of this high-risk group being exposed to SARS-CoV-2.

Other authors have also proposed the reduction in invasive disease activity associated with COVID-19 containment measures was due to suppression of direct bacterial respiratory transmission.[35] However, while nasal carriage is considered to be a precursor to invasive disease, the incidence of colonisation progressing to invasive infection is relatively low.[93] Accordingly, it has been proposed that mitigation measures may have also prevented asymptomatic carriers from progressing to invasive disease by preventing transmission of respiratory viruses, such as influenza, which are known risk factors for bacterial infection.[35, 91, 97, 98] Research from France and Israel has found that the decrease in IPD among children during COVID-19 was associated with declines in influenza and RSV and not pneumococcal nasal carriage.[97, 98]

To date, there are very few Australian studies exploring the relationship between COVID-19 NPIs, and IPD and IMD notifications and of these none have looked at age group data. However, studies conducted on a national level and in Victoria using the same NNDSS data, have shown consistent all-age IPD and IMD notification rates to our study.[52, 75]

A strength of this study is that is the only one to our knowledge that has looked at notifications of pertussis, IPD, and IMD across all Australian states and territories following the implementation of COVID-19-targeted public health measures. Accordingly, our analysis has provided a unique opportunity to evaluate the potential impact of different types and levels of COVID-19 NPIs on other respiratory infectious diseases within individual states and territories in Australia. Previous research looking at pertussis and IPD focused on single regions or states of Australia,[51, 52] and research looking at IMD was conducted nationally without state and territory stratification.[27, 75] Furthermore, unlike previous Australian research, this study has also examined age group data for pertussis, IPD, and IMD, thereby highlighting the potential impact of these measures among age groups at increased risk of infection or severe disease.

This study has some limitations. First, since it is an ecological study, it cannot demonstrate a direct causal relationship between the implementation of COVID-19 NPIs and a decrease in pertussis, IPD, and IMD notifications. Nonetheless, the consistency of results with previous studies reporting parallel declines in these infectious diseases following COVID-19 NPIs, both in Australia,[27, 51, 52] and internationally, [18, 32-35, 37, 38, 99] is compelling.

Second, consideration must be given to the possibility that disease notifications were under-reported during the pandemic period due to changes in health care-seeking behaviour; alterations to testing practices; and disruption in disease testing capacity.[6, 33, 35] It is possible that changes in health care seeking behaviour during the pandemic may have accounted for a decrease in notifications but not necessarily a parallel decrease in infections.

Nonetheless, this study demonstrated a significant and sustained decrease in pertussis notification rates among young children who are more likely to experience severe symptoms and therefore present for medical care.[45] This decrease was observed across all states and territories following the introduction of COVID-19-targeted NPIs. Within each jurisdiction the decrease seen in young children was comparable to the decrease seen across other age groups. Furthermore, due to the serious nature of invasive bacterial disease, which often presents as a medical emergency, the possibility of individuals with IPD or IMD not presenting for medical care during the pandemic period is considerably less likely.[35, 100]

The vast majority of notifications for pertussis, IPD, and IMD arise from laboratory testing.[101-103] There have been reports of reductions in the number of non-COVID-19 pathology tests conducted during the pandemic period both internationally,[104] and in Australia.[105, 106] Research exploring the impact of the pandemic on general practice pathology testing in Australia found that overall pathology testing and non-acute respiratory illness testing (non-ARI tests) decreased sharply in March 2020.[106] By June 2020, the volume of overall pathology testing recovered close to pre-pandemic levels, however, as non-ARI testing remained below pre-pandemic levels, this may suggest an increasing proportion of ARI testing within the overall testing volume.[106] Although this was likely a reflection of increased COVID-19 and influenza testing,[106] as pertussis presents with respiratory symptoms, and IPD and IMD can also present with respiratory symptoms, particularly in the presence of pneumonia,[107, 108] it is equally possible that testing for these conditions might have also increased.

A third limitation of this study is the limited age breakdown of data, particularly for infants within the 0-4 years stratum. This meant that our analysis was unable to examine the potential impact of COVID-19 NPIs within infant age groups. As children under 2 months of age and 2-3 months of age have the highest annual pertussis hospitalisation rates,[45] breakdown of infant age group data may have strengthened our methodology as changes in pertussis notifications among these groups are likely a truer estimate of pertussis infections.

Finally, disease activity and resulting notification rates can also be affected by several epidemiological factors such as geographical location, population density, population mobility, and epidemics or disease outbreaks.[109] In the case of epidemics or disease outbreaks, when applying an aggregate mean as the pre-pandemic comparison period, states and territories with epidemic peaks or disease outbreaks will have increased pre-pandemic mean notification rates, resulting in a larger rate decrease, and a stronger association between exposure and outcome. Conversely, jurisdictions without epidemics or disease outbreaks will have comparatively lower pre-pandemic mean rates, resulting in a smaller rate decrease, and the effect of NPIs might be overlooked. In this study, we attempted to minimise these impacts by excluding known epidemic and outbreak years for the reference periods for pertussis and IMD.

Sensitivity analysis was applied to pertussis and IMD to ascertain the impact of applying the same 5-year (2015 to 2019) pre-pandemic period across all studied diseases. In this analysis, for pertussis, there was a greater decrease in national all-age (1.0% to 6.5%) and age group (0% to 7.1%) pertussis notification rates, except for adults aged 70 years and over who had a smaller decrease (8.6% to 39%), when compared to the primary analysis. There was also a greater decrease in state and territory in all-age and age group pertussis notification rates (0% to 24%), except for Tasmania which had a smaller decrease (0% to 16.1%), when compared to the primary analysis. When 2015 and 2016 were included in the pre-pandemic period, this deflated the estimated decrease for Tasmania. As the pertussis epidemic peaked asynchronously across jurisdictions, Tasmania had very low pertussis notifications in 2015 and 2016 which increased in 2018 and peaked much later in 2019. Therefore, our primary analysis may have overestimated the decrease in pertussis notifications observed in Tasmania.

For IMD, when the outbreak year 2017 was included in the pre-pandemic period, there was a greater decrease in national all-age (3.6% to 4.4%) and age group (0.5% to 37.8%) IMD notification rates, when compared to the primary analysis. There was also a greater decrease in state and territory in all-age IMD notification rates (1.1% to 20.0%) with the greatest decrease observed in the Northern Territory, the outbreak epicentre (19.9% to 20.0%). Overall, the results of sensitivity analysis suggest that the findings in the primary analysis are more likely conservative estimates.

While the considerable decrease observed in pertussis, IPD, and IMD associated with COVID-19 NPIs may have collateral public health benefits, the reduction in bacterial circulation may have also resulted in reduced natural immunity, thereby exposing vulnerable populations to future disease outbreaks.[32, 33, 54, 97] Routine vaccination coverage across all ages and high-risk groups should be optimised to mitigate this risk. While some countries have reported a decrease in routine vaccine administration during the pandemic,[110, 111] evidence suggests that in Australia the impact on vaccination rates during the pandemic has been marginal. Data from the Australian Department of Health and Aged Care showed that in 2021, Queensland, the Northern Territory, and Tasmania had a decrease in childhood vaccination coverage compared to the 2019 coverage rate but this was less than 2%.[112] It would be beneficial to review the 2022 data as it is important that these states and territories address vaccination coverage to minimise any risk of incomplete coverage increasing disease activity.

In South Africa, there have been reports of a recent surge in pertussis activity with notifications rising steeply between July and September 2022, following a low number of notifications in 2020 and 2021. Infants and young children accounted for over 70% of cases.[113]

In England, a sharp increase in IMD caused by MenB was observed among adolescents and young adults in late 2021, following the easing of COVID-19 public health measures.[114] It was proposed that pandemic lockdowns likely reduced meningococcal exposure and nasal carriage among this cohort. The increase in disease was possibly due to a rapid increase in nasal carriage and disease transmission as these populations returned to school and university.[114]

In Australia, a resurgence of some respiratory viruses above pre-pandemic levels has already been observed after the easing of pandemic control measures. In Western Australia, an earlier than usual resurgence of RSV was observed from late September 2020, following a period of staged relaxed social distancing measures after the first national lockdown and coinciding with the lifting of Western Australia's hard border to a controlled interstate border.[115] Furthermore, recent epidemiological data has shown laboratory confirmed influenza A notifications in Australia increased sharply from low levels and to an earlier than usual peak in June 2022.[116] Notifications climbed well above what was recorded during the same period in 2019 and were above the 2017 to 2021 mean, but dropped rapidly in July.[116, 117] As the overall impact of the 2022 influenza season was low to moderate, (reflected by the rate of Flu Tracking respondents absent from regular duties and the number of influenza hospitalisations),[117] it is likely that high influenza notifications may have also reflected changed testing patterns.

Nonetheless, the possibility of increasing circulation of respiratory viruses following lifting of COVID-19 NPIs has implications for invasive disease outbreaks. Studies reporting predominantly unchanged rates of pneumococcal nasal carriage during the pandemic suggest there was no decrease in natural immunity to pneumococcal serotypes.[97, 98] Rather, the close association between the incidence of IPD and seasonal respiratory viruses may have implications for future prevention of IPD cases.[97] While it has been hypothesised that an influenza outbreak might trigger an increase in IPD or IMD,[27, 97, 118] recent Australian surveillance data suggests there has been no resurgence of IMD, and IPD notifications remain below the 2016 to 2021 mean.[119]

5. Conclusion

In conclusion, this study has demonstrated a significant decrease in three clinically significant bacterial infections, pertussis, IPD, and IMD, following the implementation of COVID-19 targeted NPIs in Australia. For pertussis, national notifications declined markedly with all states and territories demonstrating a substantial and sustained decrease in notifications. For pertussis, IPD, and IMD, some of the largest declines in notifications were observed among age groups at high risk of infection or severe disease. Notably, for pertussis, the observed decrease in notifications among young children might negate the possibility of under-notification during the pandemic period. Further comparison with hospitalisation data would also be useful as this data should not be subject to under-notification issues.

While it was not possible to establish which NPIs had the greatest individual impact in reducing disease transmission, this study demonstrated that there may have been differential impacts of certain NPIs in reducing the transmission of pertussis, IPD, and IMD. For pertussis, hard border closures and stringent border restrictions appeared to have had a greater impact on notification rates within jurisdictions with low pre-pandemic disease rates, whereas for IPD and IMD, mandates impacting individual proximity may have had a greater influence on notifications rates within jurisdictions with high pre-pandemic disease rates.

Finally, while the introduction of COVID-19-targeted NPIs may have had considerable public health benefits, there is potential risk of a resurgence in pertussis, IPD, and IMD. Through dissemination of targeted public health messaging, it is important that routine vaccination rates, particularly among high-risk groups, remain high. Furthermore, as maternal vaccination reduces the risk of pertussis in young infants by 90%,[120] these rates should also be monitored closely over the coming months.[34, 54]

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7. Appendices

7.1 Appendix A: Supplementary tables and figures

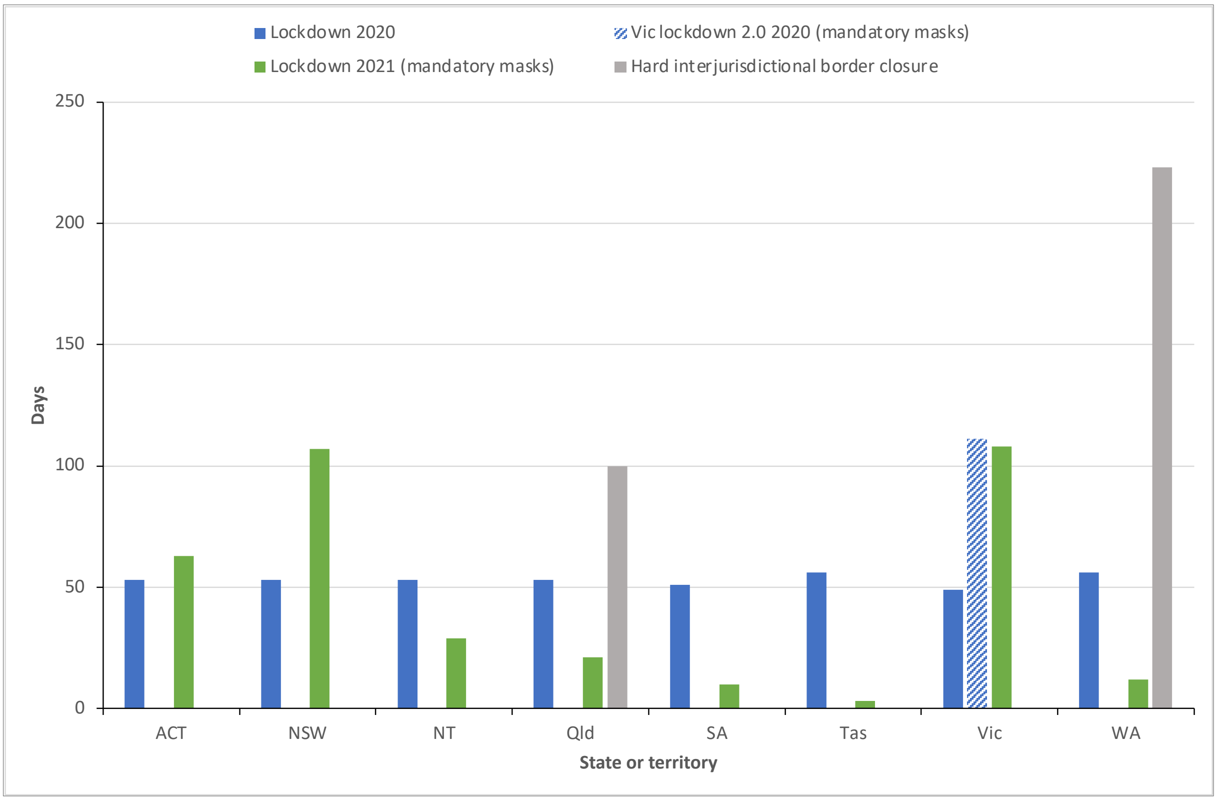

Figure A1. Total number of lockdown days with associated mask mandates and hard interjurisdictional border closures for each Australian state and territory during 2020 and 2021.

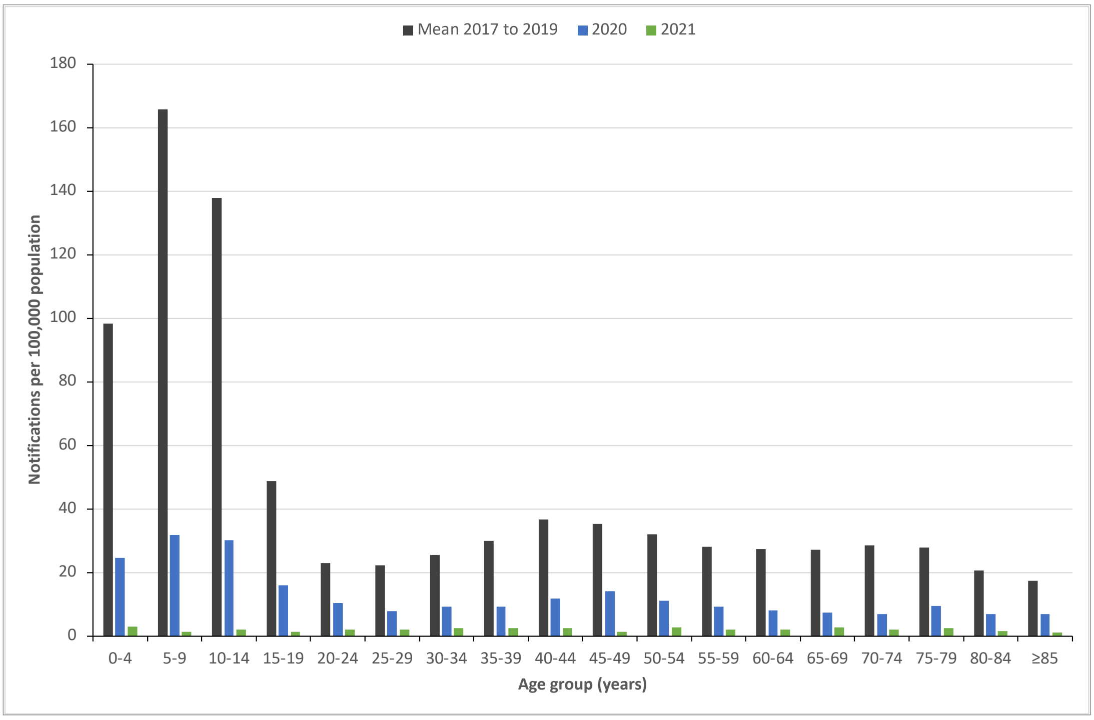

Figure A2. Australian national pertussis notification rates by 5-year age group showing annual rates for 2020 and 2021 compared to the 2017 to 2019 mean annual notification rate.

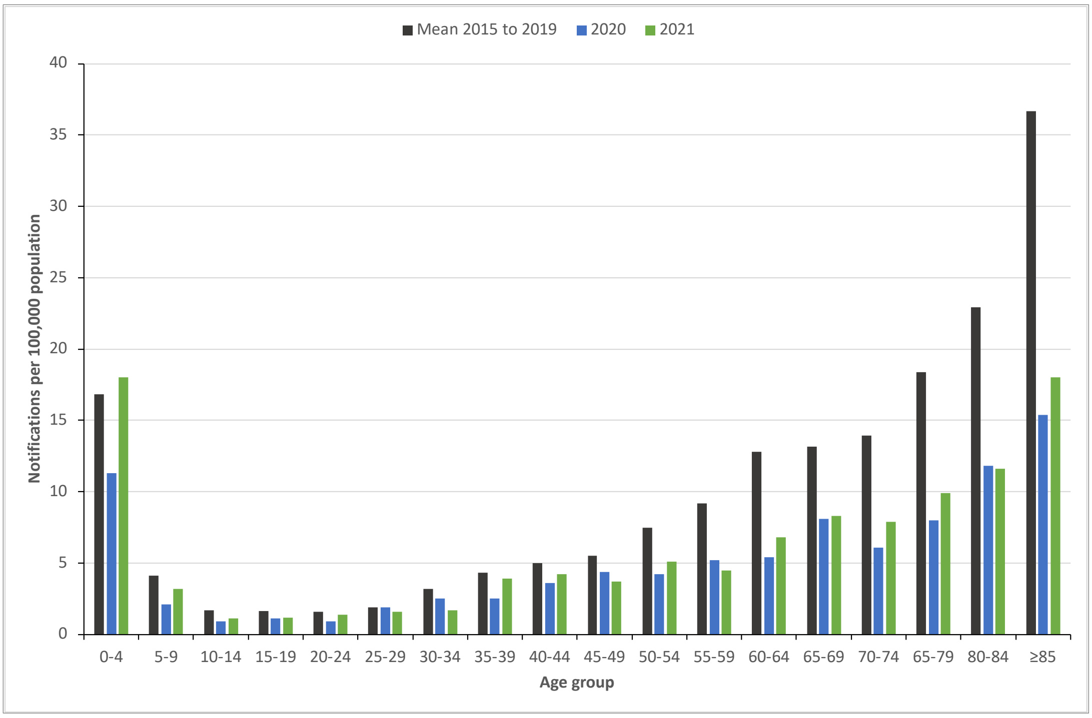

Figure A3. Australian national invasive pneumococcal disease notification rates by 5-year age group showing annual rates for 2020 and 2021 compared to the 2015 to 2019 mean annual notification rate.

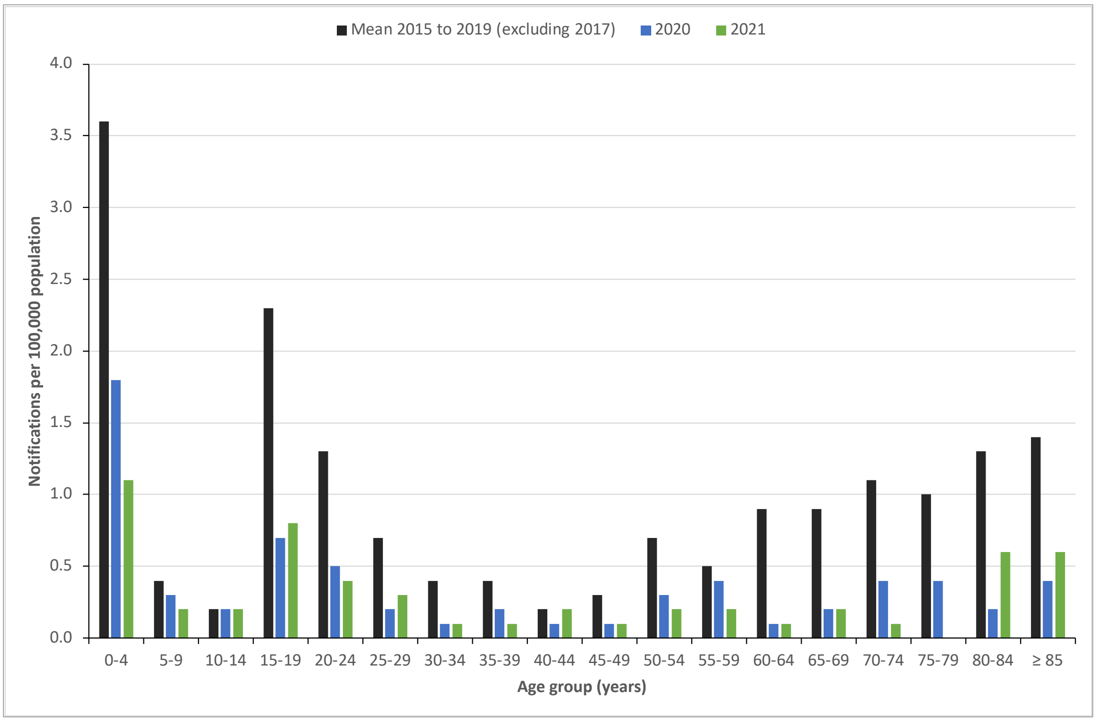

Figure A4. Australian national invasive meningococcal disease notification rates by 5-year age group showing 2020 and 2021 compared to the 2015 to 2019 (excluding 2017) mean annual notification rate.

Table A1. Timeline of Australian state and territory COVID-19 public health measures showing lockdowns, mask mandates, and hard interjurisdictional border closures, March 2020 to December 2021.

Date of restriction commencement	Date of restriction easing	Public heath measure	Additional details
ACT			
2020			
March 23, 2020	May 15, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
2021			
August 12, 2021	October 14, 2021	Lockdown, mask mandate	Territory-wide lockdown. [2, 3] During the lockdown period, mask wearing mandatory outside the home at all times for those aged 12 years and over. Mask mandates lifted on November 10, 2021. [4]
NSW			
2020			
March 23, 2020	May 15, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
2021			
June 26, 2021	October 11, 2021	Lockdown, mask mandate	Lockdown for Greater Sydney Region. [5, 6] Regional New South Wales placed in lockdown from August 14, 2021 to October 11, 2021. [7] Mask wearing mandatory in all in-door non-residential settings from June 26, 2021 to December 15, 2021[5, 8]
NT			
2020			
March 23, 2020	May 15, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
2021			
June 26, 2021	July 2, 2021	Lockdown, mask mandate	Lockdown for Greater Darwin[9, 10]
August 16, 2021	August 20, 2021	Lockdown, mask mandate	Lockdown for Greater Darwin, Wagait Shire, Belyuen Shire, Dundee, Bynoe, Charlotte, Cox Peninsula, and municipality of Katherine[11]
November 5, 2021	November 9, 2021	Lockdown, mask mandate	Lockdown for Katherine[12]
November 15, 2021	November 27, 2021	Lockdown, mask mandate	Lockdown for Katherine[13, 14]
December 17, 2021	December 20, 2021	Lockdown, mask mandate	Lockdown for Tennant Creek[15]
Qld			
2020			
March 23, 2020	May 15, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
April 3, 2020	July 10, 2020	Hard border closure	Only Queensland residents and those with an exception allowed to enter the state. [1]
2021			
January 8, 2021	January 11, 2021	Lockdown, mask mandates	Lockdown for Greater Brisbane[16]
March 29, 2021	April 1, 2021	Lockdown, mask mandates	Lockdown for Greater Brisbane[17]
April 1, 2021	April 15, 2021	Mask mandates	State-wide mandatory mask wearing in all indoor non-residential settings[18]
June 29, 2021	July 3, 2021	Lockdown, mask mandates	Lockdown for Greater Brisbane and 10 additional local government areas along South Eastern Queensland[19, 20]
July 31, 2021	August 11, 2021	Lockdown, mask mandates	Lockdown for Greater Brisbane and 10 additional local government areas along South Eastern Queensland[21, 22]
June 29, 2021	November 11, 2021	Mask mandates	South Eastern Queensland had mandatory mask wearing in all indoor non-residential settings. [23]

Table A1. Continued

Date of restriction commencement	Date of restriction easing	Public heath measure	Additional details
SA			
2020			
March 23, 2020	May 11, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
November 19, 2020	November 22, 2020	Lockdown	State-wide circuit breaker lockdown[24]
July 20, 2021	July 28, 2021	Lockdown, mask mandates	State-wide lockdown[25, 26]
Tas			
2020			
March 23, 2020	May 18, 2021	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
2021			
October 15, 2021	October 18, 2021	Lockdown, mask mandates	Lockdown for Southern Tasmania[27]
Vic			
2020			
March 23, 2020	May 11, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
July 8, 2020	October 27, 2020	Lockdown, mask mandates	Stage 3 'Stay Home' lockdown implemented across metropolitan Melbourne and Mitchell Shire on July 8, 2020 [28], with elevation to stricter Stage 4 restrictions (including curfew) from August 2, 2020. [29] Regional Victoria entered Stage 3 ' Stay Home' restrictions on August 4, 2020. [30] Restrictions eased incrementally, with lifting of Stage 4 restrictions on September 13, 2020 [31], and Stage 3 restrictions on October 27, 2020. [32]
February 12, 2021	February 17, 2021	Lockdown, mask mandates	State-wide lockdown[33]
May 27, 2021	June 10, 2021	Lockdown, mask mandates	State-wide lockdown[34, 35]
July 15, 2021	July 27, 2021	Lockdown, mask mandates	State-wide lockdown[36, 37]
August 5, 2021	October 21, 2021	Lockdown, mask mandates	State-wide lockdown[38, 39]
February 12, 2021	December 15, 2021	Mask mandates	During lockdown masks mandatory at all times outside the home. From October 29, 2021, masks no longer required outdoors, but remained mandatory in-doors until December 15, 2021. [40, 41]
WA			
2020			
March 23, 2020	May 18, 2020	Lockdown	Nationwide lockdown on advice of National Cabinet. [1]
April 5, 2020	November 14, 2020	Hard border closure	Hard borer closure to all other states and territories. [1]
2021			
January 31, 2021	February 5, 2021	Lockdown, mask mandates	Lockdown for Perth, Peel, and the South West [42]
April 24, 2021	April 27, 2021	Lockdown, mask mandates	Lockdown for Perth and Peel[43]
June 29, 2021	July 3, 2021	Lockdown, mask mandates	Lockdown for Perth and Peel[44]

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7.2 Appendix B: Sensitivity analysis

Table A2. Pertussis notification rates for 2020 and 2021 compared to the 2015 to 2019 mean annual rate, by jurisdiction and age group, Australia.

Jurisdiction and age group	2015-2019 mean	2020	2021	IRR 2020 vs. 2015-2019 (95% CI)	IRR 2021 vs. 2015-2019 (95% CI)
ACT					
0-4 years	92.7	14.4	0.0	0.16 (0.04 – 0.45)	0.00 (0.00 – 0.16)
5-14 years	226.7	21.6	1.8	0.10 (0.05 – 0.18)	0.01 (0.00 – 0.05)
15-24 years	66.7	19.0	0.0	0.29 (0.14 – 0.56)	0.00 (0.00 – 0.10)
25-69 years	65.1	8.3	2.6	0.13 (0.08 – 0.20)	0.04 (0.02 – 0.09)
≥ 70 years	70.2	2.5	7.1	0.04 (0.00 – 0.23)	0.11 (0.02 – 0.35)
Overall	87.8	11.8	2.5	0.14 (0.10 – 0.18)	0.03 (0.01 – 0.05)
NSW					
0-4 years	261.9	43.4	1.7	0.17 (0.14 – 0.19)	0.01 (0.00 – 0.01)
5-14 years	379.4	47.0	0.5	0.12 (0.11 – 0.14)	0.00 (0.00 – 0.00)
15-24 years	70.4	13.9	0.4	0.20 (0.16 – 0.24)	0.01 (0.00 – 0.02)
25–69 years	50.7	9.6	0.4	0.19 (0.17 – 0.21)	0.01 (0.01 – 0.01)
≥ 70 years	32.3	5.6	0.4	0.17 (0.13 – 0.23)	0.01 (0.00 – 0.03)
Overall	105.1	16.2	0.5	0.16 (0.15 – 0.16)	0.00 (0.00 – 0.01)
NT					
0-4 years	73.4	5.6	5.7	0.08 (0.00 – 0.50)	0.08 (0.00 – 0.50)
5-14 years	103.0	22.9	0.0	0.22 (0.09 – 0.48)	0.00 (0.00 – 0.11)
15-24 years	28.5	6.1	0.0	0.20 (0.02 – 0.96)	0.00 (0.00 – 0.46)
25-69 years	25.5	2.6	2.0	0.10 (0.03 – 0.29)	0.08 (0.25 – 0.25)
≥ 70 years	22.6	0.0	0.0	0.00 (0.00 – 0.25)	0.00 (0.00 – 4.12)
Overall	40.4	6.1	1.6	0.15 (0.08 – 0.26)	0.04 (0.01 – 0.11)
Qld					
0-4 years	71.4	6.2	5.3	0.09 (0.05 – 0.14)	0.07 (0.04 – 0.12)
5-14 years	125.6	25.7	4.9	0.20 (0.17 – 0.24)	0.04 (0.03 – 0.06)
15-24 years	24.1	11.1	1.7	0.46 (0.34 – 0.61)	0.07 (0.03 – 0.13)
25-69 years	18.6	6.4	1.1	0.34 (0.29 – 0.41)	0.06 (0.04 – 0.08)
≥ 70 years	12.0	5.9	1.0	0.49 (0.31 – 0.76)	0.08 (0.03 – 0.19)
Overall	36.1	9.5	1.9	0.26 (0.24 – 0.29)	0.05 (0.04 – 0.06)
SA					
0-4 years	122.5	18.3	5.1	0.15 (0.09 – 0.24)	0.04 (0.01 – 0.10)
5-14 years	228.4	21.1	0.5	0.09 (0.07 – 0.13)	0.00 (0.00 – 0.01)
15-24years	51.4	21.6	0.5	0.42 (0.29 – 0.59)	0.01 (0.00 – 0.05)
25-69 years	43.3	15.8	1.7	0.37 (0.30 – 0.44)	0.04 (0.02 – 0.06)
≥ 70 years	36.2	6.6	3.2	0.19 (0.10 – 0.32)	0.09 (0.04 – 0.19)
Overall	70.1	16.2	1.8	0.23 (0.20 – 0.26)	0.03 (0.02 – 0.04)

Table A2. Continued

Jurisdiction and age group	2015-2019 mean	2020	2021	IRR 2020 vs. 2015-2019 (95% CI)	IRR 2021 vs. 2015-2019 (95% CI)
Tas					
0-4 years	79.4	40.5	0.0	0.51 (0.23 – 1.05)	0.00 (0.00 – 0.17)
5-14 years	157.8	28.6	0.0	0.18 (0.10 – 0.29)	0.00 (0.00 – 0.04)
15-24 years	33.6	1.6	0.0	0.05 (0.00 – 0.28)	0.00 (0.00 – 0.19)
25-69 years	19.6	9.5	1.5	0.47 (0.30 – 0.74)	0.08 (0.02 – 0.19)
≥ 70 years	10.8	2.6	1.2	0.22 (0.02 – 1.10)	0.11 (0.00 – 0.79)
Overall	40.9	12.0	1.1	0.29 (0.22 – 0.38)	0.03 (0.01 – 0.06)
Vic					
0-4 years	53.3	25.6	3.9	0.48 (0.38 – 0.62)	0.07 (0.04 – 0.12)
5-14 years	80.4	29.2	1.7	0.37 (0.31 – 0.43)	0.02 (0.01 – 0.04)
15-24 years	25.7	15.1	4.6	0.59 (0.47 – 0.74)	0.18 (0.12 – 0.26)
25-69 years	38.3	13.9	5.7	0.37 (0.33 – 0.41)	0.15 (0.13 – 0.17)
≥ 70 years	43.6	14.1	3.7	0.33 (0.26 – 0.42)	0.09 (0.06 – 0.13)
Overall	43.1	16.4	4.7	0.39 (0.36 – 0.41)	0.11 (0.10 – 0.12)
WA					
0-4 years	90.7	5.8	0.0	0.06 (0.03 – 0.12)	0.00 (0.00 – 0.02)
5-14 years	102.1	7.6	0.3	0.08 (0.05 – 0.11)	0.00 (0.00 – 0.02)
15-24 years	35.3	4.3	0.6	0.12 (0.06 – 0.21)	0.02 (0.00 – 0.06)
25-69 years	39.7	3.9	2.3	0.10 (0.08 – 0.13)	0.06 (0.04 – 0.08)
≥ 70 years	51.1	4.2	2.3	0.08 (0.04 – 0.15)	0.05 (0.02 – 0.10)
Overall	52.6	4.7	1.8	0.09 (0.07 – 0.11)	0.03 (0.02 – 0.04)
Australia					
0-4 years	133.4	24.5	3.0	0.18 (0.16 – 0.20)	0.02 (0.02 – 0.03)
5-14 years	201.2	30.9	1.7	0.15 (0.14- 0.16)	0.01 (0.01 – 0.01)
15-24 years	43.1	13.0	1.7	0.31 (0.28 – 0.35)	0.04 (0.03 – 0.06)
25-69 years	38.7	9.8	2.3	0.26 (0.25 – 0.28)	0.06 (0.05 – 0.07)
≥ 70 years	33.3	7.6	2.3	0.66 (0.56 – 0.76)	0.16 (0.12 – 0.21)
Overall	64.9	13.5	2.1	0.21 (0.20 – 0.22)	0.03 (0.03 – 0.04)

Table A3. Invasive meningococcal disease notification rates for 2020 and 2021 compared to the 2015 to 2019 mean annual rate by jurisdiction, Australia.

Jurisdiction	2015-2019 mean	2020	2021	IRR 2020 vs. 2015-2019 (95% CI)	IRR 2021 vs. 2015-2019 (95% CI)
ACT and NSW	0.8	0.3	0.3	0.32 (0.19 – 0.52)	0.32 (0.19 – 0.52)
NT	4.2	0.8	0.8	0.20 (0.02 – 0.94)	0.20 (0.02 – 0.94)
Qld	1.0	0.5	0.3	0.51 (0.31 – 0.84)	0.26 (0.13 – 0.49)
SA	1.8	0.3	0.7	0.16 (0.05 – 0.41)	0.38 (0.18 – 0.75)
Tas	1.9	0.6	0.4	0.29 (0.05 – 1.13)	0.19 (0.02 – 0.91)
Vic	1.0	0.3	0.2	0.28 (0.16 – 0.48)	0.16 (0.08 – 0.31)
WA	1.1	0.4	0.4	0.35 (0.16 – 0.73)	0.32 (0.14 – 0.67)
Australia	1.1	0.4	0.3	0.33 (0.26 – 0.42)	0.27 (0.21 – 0.35)

Medicine & Health Sciences Subcommittee
Macquarie University, North Ryde
NSW 2109, Australia

22/04/2022

Dear Professor Amin,

Reference No: 520221151037299
Project ID: 11510
Title: Respiratory vaccine preventable diseases in the time of COVID-19

Approval date: 22 April 2022

Thank you for submitting the above application for ethical review. The Medicine & Health Sciences Subcommittee has considered your application.

I am pleased to advise that ethical approval has been granted for this project to be conducted by Professor Amin, and other personnel: Dr Aditi Dey, Associate Professor Frank Beard, and Mrs Saskia van der Kooi.

This research meets the requirements set out in the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the National Statement, available from the following website: https://nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018.

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol - 22 April. You will be sent an automatic reminder email one week from the due date to remind you of your reporting responsibilities. Please report using the following reporting periods;

    Annual report 1 - FROM 22/04/2022 TO 22/04/2023

    Annual report 2 - FROM 22/04/2023 TO 22/04/2024

    Annual report 3 - FROM 22/04/2024 TO 22/04/2025

    Annual report 4 - FROM 22/04/2025 TO 22/04/2026

    Final report 5 - FROM 22/04/2026 TO 22/04/2027

3. All adverse events, including unforeseen events, which might affect the continued ethical acceptability of the project, must be reported to the subcommittee within 72 hours.

4. All proposed changes to the project and associated documents must be submitted to the subcommittee for review and approval before implementation via the Human Research Ethics Management System.

The HREC Terms of Reference and Standard Operating Procedures are available from the Research Services website: https://www.mq.edu.au/research/ethics-integrity-and-policies/ethics/human-ethics.

It is the responsibility of the Chief Investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Faculty Ethics Officer.

The Medicine & Health Sciences Subcommittee wishes you every success in your research.

Yours sincerely,

Dr Mark Butlin

Chair, Medicine & Health Sciences Subcommittee

The Faculty Ethics Subcommittees at Macquarie University operate in accordance with the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018), [Section 5.2].