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Dimensions of equality in uptake of COVID-19 vaccination in Wales, UK: A multivariable linked data population analysis

Gethin Jones [a,*], Malorie Perry [a,b], Rowena Bailey [b], Sudha Arumugam [b], Adrian Edwards [c], Alex Lench [a], Alison Cooper [c], Ashley Akbari [b], Brendan Collins [d,e], Caroline Harris [a], Gill Richardson [f], Mai Barry [a], Phillippa Harris [a], Richard Fry [b], Ronan A. Lyons [b], Simon Cottrell [a]

[a] Vaccine Preventable Disease Programme and Communicable Disease Surveillance Centre, Public Health Wales, 2 Capital Quarter, Tyndall Street, Cardiff CF10 4BZ, Wales, UK
[b] Population Data Science, Swansea University Medical School, Faculty of Medicine, Health & Life Science, Swansea University Swansea, SA2 8PP Wales, UK
[c] Wales COVID-19 Evidence Centre, PRIME Centre Wales, Division of Population Medicine, School of Medicine, Cardiff University, 8th Floor, Neuadd Meirionnydd, Heath Park, Cardiff CF14 4XN, Wales, UK
[d] Health and Social Services Group, Health Protection, Welsh Government, Cardiff, UK
[e] Department of Public Health, Policy and Systems, University of Liverpool, UK
[f] Policy, Research and International Development, Public Health Wales, 2 Capital Quarter, Tyndall Street, Cardiff CF10 4BZ, Wales, UK

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ABSTRACT

Vaccination has proven to be effective at preventing severe outcomes of COVID-19 infection, and uptake in the population has been high in Wales. However, there is a risk that high-level vaccination coverage statistics may mask hidden inequalities in under-served populations, many of whom may be at increased risk of severe outcomes of COVID-19 infection.

The study population included 1,436,229 individuals aged 18 years and over, alive and residence in Wales as at 31st July 2022, and excluded immunosuppressed or care home residents. We compared people who had received one or more vaccinations to those with no vaccination using linked data from nine datasets within the Secure Anonymised Information Linkage (SAIL) databank. Multivariable analysis was undertaken to determine the impact of a range of sociodemographic characteristics on vaccination uptake, including ethnicity, country of birth, severe mental illness, homelessness and substance use.

We found that overall uptake of first dose of COVID-19 vaccination was high in Wales (92.1 %), with the highest among those aged 80 years and over and females. Those aged under 40 years, household composition (aOR 0.38 95 %CI 0.35–0.41 for 10+ size household compared to two adult household) and being born outside the UK (aOR 0.44 95 %CI 0.43–0.46) had the strongest negative associations with vaccination uptake. This was followed by a history of substance misuse (aOR 0.45 95 %CI 0.44–0.46).

Despite high-level population coverage in Wales, significant inequalities remain across several underserved groups. Factors associated with vaccination uptake should not be considered in isolation, to avoid drawing incorrect conclusions. Ensuring equitable access to vaccination is essential to protecting under-served groups from COVID-19 and further work needs to be done to address these gaps in coverage, with focus on tailored vaccination pathways and advocacy, using trusted partners and communities.

* Corresponding author.
E-mail addresses: Gethin.Jones6@wales.nhs.uk (G. Jones), Malorie.Perry@wales.nhs.uk (M. Perry), R.Bailey@swansea.ac.uk (R. Bailey), Sudha.Arumugam@ukhsa.gov.uk (S. Arumugam), Edwardsag@cardiff.ac.uk (A. Edwards), Alex.Lench@wales.nhs.uk (A. Lench), Coopera8@cardiff.ac.uk (A. Cooper), A.Akbari@swansea.ac.uk (A. Akbari), Brendan.Collins001@gov.wales (B. Collins), Caroline.Harris2@wales.nhs.uk (C. Harris), Gill.Richardson2@wales.nhs.uk (G. Richardson), Mai.Barry@wales.nhs.uk (M. Barry), Phillippa.Harris@wales.nhs.uk (P. Harris), R.J.Fry@swansea.ac.uk (R. Fry), R.A.Lyons@Swansea.ac.uk (R.A. Lyons), Simon.Cottrell@wales.nhs.uk (S. Cottrell).

1. Background

The COVID-19 mass-vaccination programme, which began for adults in December 2020 [1], achieved high levels of uptake in the population at pace, administering vaccines that prevented severe outcomes of COVID-19 infection [2].

Uptake of COVID-19 vaccination at a population level was the highest achieved in recent history for adults in Wales, however high-level vaccination coverage statistics may mask inequalities. Groups and individuals who are under-served from many perspectives often have lower vaccination uptake rates and may face additional challenges that place them at higher risk of severe outcomes to infections. Ensuring equity in vaccine opportunity, awareness, understanding and access is therefore essential to protecting the health of these population groups.

In order to understand underlying barriers to immunisation and develop successful interventions to increase coverage, there is a need to identify who is under-vaccinated (either unvaccinated or incompletely vaccinated) and the common characteristics associated with increased risk of under-vaccination.

This research builds on previously published data highlighting lower COVID-19 vaccination uptake associated with some ethnic groups, increased socio-economic deprivation [3], and according to different household compositions [4]. We include other under-served groups, including people who may be 'invisible' to routine surveillance data, including those with lived experience of homelessness [5], those with a history of substance use problems [6] and those with severe mental illness [7], all of whom have been observed previously to have low levels of vaccination uptake [8–11], and often face barriers to healthcare access [12,13].

Previous research has shown that some of the association between ethnicity and increased risk of severe outcomes related to COVID-19 is confounded by deprivation [14,15].

Socioeconomic deprivation and vulnerability are complex and are potentially both additive and compounding. Root-causes for low vaccination uptake in these groups are often multi-faceted, and their relative contribution to uptake rates is difficult to identify. We therefore aimed to examine the effect of a range of key factors on vaccination coverage across the population eligible for COVID-19 primary vaccination in Wales, UK.

2. Methods

All data were accessed and analysed within the Secure Anonymised Information Linkage (SAIL) Databank hosted by Swansea University. This analysis formed part of the Con-COV project (Controlling COVID-19 project) [16,17]. The cohort included all those aged 18 years and over, alive and resident in Wales as at 31st July 2022 as identified via the Welsh Demographic Service Dataset (WDSD), and excluded any individuals identified as immunosuppressed or care home residents who were on different schedules or primarily vaccinated in their place of residence.

For the principal outcome of vaccine uptake, we assessed people aged 18 years and over who had received one or more vaccinations versus those with no record of COVID-19 vaccination as at 31st July 2022. The majority of individuals would have been offered their primary course in the first half of 2021, and the majority of which would have been offered vaccination within a Mass Vaccination Centre. During the vaccination period covered in this study, those administering vaccination in Wales were instructed to record these details within the Welsh Immunisation System, which feeds into the COVID-19 vaccination register dataset (CVVD) within SAIL.

Vaccination status was derived from the all Wales COVID-19 vaccination register dataset (CVVD), whilst sex, health board (geographical area) of residence, ethnic group, deprivation quintile (according to Welsh Index of Multiple Deprivation), urban/rural location of residence, household composition, QCOVID comorbidity score and those with

lived-experience of homelessness were assigned as previously described [3,4,18,19].

Individuals with severe mental illness were identified using Read coded general practice (WLGP) records for disorders highlighted within the PRIMIS COVID-19 specification for identifying those at increased clinical risk [20]. These data were supplemented using the International Classification of Diseases version 10 (ICD-10) codes recorded within Patient Episode Database Wales (PEDW), which records data on hospital episodes in Wales. Read codes were translated to ICD-10 codes using an online converter [21].

Identification of those with a history of substance misuse was completed using the Welsh National Database for Substance Misuse (SMDS), which includes data on people referred for treatment for a substance misuse problem and information on what substances they use. The data source covers most of the services the Welsh Government funds [22]. A flag was created for those with any record in the SMDS since 2014.

Recorded first language was assigned using a hierarchical approach to those data sources which contained this information. Language was as recorded in the 2011 Office for National Statistics (ONS) Census data (CENW), or as recorded in WLGP data, or as recorded in Welsh Ambulance Service Data (WASD). For people whose language was not available in any of these three data sources, individuals were assumed to be English/Welsh speakers if there was a birth record in the ONS Annual District Birth Extract (ADBE) data for Wales. Information on country of birth was taken from the CENW or ADBE, and where this was unavailable, it was as recorded in WLGP.

Physical disability was flagged using data from CENW and an individual's response to question 23: *"Are your day-to-day activities limited because of a health problem or disability which has lasted, or is expected to last, at least 12 months?"*. Uptake was calculated against each of the three multiple-choice responses: *"1) Yes, limited a lot; 2) Yes, limited a little; 3) No"*. The method used in constructing these categories is based on the Measuring disability for Equality Act 2010 harmonisation guidance [23].

Hearing and sight loss were flagged using a list of Read codes published by Cambridge University [24]. Individuals with one of these codes were identified using WLGP data.

To ascertain vaccination uptake within the Welsh Index of Multiple Deprivation (WIMD) domains (physical environment, community safety, housing, access to services, education), data were taken from CVVD and linked by Lower-layer Super Output Area version 2011 (LSOA 2011, i.e. locality) of residence to the 2019 WIMD domain ranking dataset [25]. Data were allocated into quintiles for each domain rank to provide an indication of the deprivation status for the domains of the LSOA of residence.

Differences between the study population and general population were assessed using chi-squared tests, and the associated p-value recorded.

In addition to looking at urban/rural location of residence, as described previously [3], distance to the nearest Mass Vaccination Centre from an individuals' household within the same Health Board was calculated in km by road and introduced as a continuous variable.

An initial univariable analysis was completed to identify which variables to include in the multivariable analysis, using logistic regression. All variables identifying an association with statistical significance of at least $p < 0.05$ were taken forward to multivariable analysis. Variables were added in a forward stepwise manner, in order of strength of association with vaccination uptake, into the multivariable logistic regression model. Variables with co-linearity, as indicated by a Variance Inflation Factor (VIF) greater than 5 (Overall WIMD quintile, Income domain, Health domain, Employment domain), or those which provided no improvement in Akaike information criterion (Rurality and Sight loss) were not included in the final model. A complete case analysis approach was used as inclusion criteria, limiting analysis to those who had no missing information across final model variables. Model

coefficients were exponentiated and are reported as odds ratios along with corresponding 95 % confidence intervals. Analysis was completed using the software package R studio (version 4.1.3).

3. Results

3.1. Study population

There were 2,421,523 individuals in the general population, aged 18 years and over, alive and resident in Wales at 31st July 2022. A total of 1,436,229 were included in the final study population. This excludes 15,950 individuals who were flagged as residents in a care home, 80,293 who were immunosuppressed, 297,372 individuals who were registered to GPs who do not submit data to SAIL databank and 591,679 who had incomplete information across the variables of interest. The composition of the study population was similar to that of the general population (Table 1). The proportion of those in the combined White ethnic group was larger in the study population than is observed in the general population, largely owing to those individuals in the study whose ethnic group is not known and were consequently excluded from analysis. Similarly, there was a larger proportion of those whose first language was English or Welsh and of those born in the UK in the study population compared to the general population. There was also a smaller proportion of those in many of the most deprived quintiles of the WIMD domains in the study population compared with the general population.

3.2. Univariable analyses

All results were significant at the 0.05 level in the univariable analysis except for distance from a Mass Vaccination Centre. Female sex, a higher comorbidity score, hearing loss, increased age and physical disability were all positive predictors of vaccination uptake in the univariable analysis (Table 2). Being a resident in the least deprived quintile, compared to the most deprived quintile, was positively associated with vaccination uptake for a number of WIMD domains (physical environment, community safety, housing, access to services, and education). Severe mental illness, history of substance misuse, lived experience of homelessness, first language not being English/Welsh, being born outside the UK, ethnic group other than those in the combined White ethnic group, and household composition were all negatively associated with vaccination uptake (Table 2).

The univariable analysis highlighted household composition, ethnic group and age as the largest influence on vaccination uptake. Within the household composition category, having a household size of 10 + saw the largest deviation from the reference group of two adults sharing a house (OR 0.15 95 % CI 0.14–0.16), followed by large adult group (single generation) (OR 0.17 95 % CI 0.14–0.21). Within the ethnic group category, compared to the combined White ethnic group, those in the combined Black ethnic group were found to have the lowest vaccination coverage (OR 0.25 95 % CI 0.23–0.26). Being aged 80 years and over saw the largest deviation from the reference group of those aged 50–59 years (OR 3.69 95 % CI 3.50–3.89) and declined with each lower age band.

3.3. Multivariable analysis

The multivariable analysis showed that after controlling for all other variables, those aged under 40 years, household composition and being born outside the UK had the strongest negative associations with vaccination uptake (Table 2). This was followed by a history of substance misuse and increasing QCOVID comorbidity score. As in the univariable analysis, vaccination uptake varied by age, but those aged 80 years and over remained the most likely to be vaccinated (aOR 3.52 95 % CI 3.33–3.71). Those with a household size of 10 + saw a slight improvement in vaccination uptake in the multivariable analysis but remained low (aOR 0.38 95 % 0.35——0.41). Those born outside the UK

saw little difference in odds of being vaccinated in the univariable and multivariable analysis, and also remained low (aOR 0.44 95 % CI 0.43–0.46).

The negative association of being vaccinated within the substance misuse category was less pronounced when all other factors were considered, a history of substance misuse saw a reduced likelihood of being vaccinated (aOR 0.45 95 % CI 0.44–0.46) compared to those without. A similar result was found for both people with severe mental illness (aOR 0.64 95 % CI 0.59–0.71) and those with lived experience of homelessness (aOR 0.58 95 % CI 0.55–0.61). The odds of being vaccinated among people with a QCOVID comorbidity score of 5 + fell significantly when all other factors were considered within the multivariable analysis but remained high (aOR 2.10 95 % CI 1.91–2.32).

Although the univariable analysis showed those with a physical disability were more likely to be vaccinated compared to those without, after controlling for all other variables, those with a physical disability were less likely to be vaccinated compared to those without. This was true for both those reporting being "limited a little" (aOR 0.75 95 % CI 0.73–0.77) and those reporting being "limited a lot" (aOR 0.63 95 % CI 0.62–0.65). Similarly, those in the combined Asian ethnic group were more likely to be vaccinated compared to those in the combined White ethnic group when all other factors were considered (aOR 1.68 95 % CI 1.61–1.76).

4. Discussion

4.1. Principal findings

This study provides novel evidence of COVID-19 vaccination uptake within under-served groups and among a variety of sociodemographic characteristics, covering all adults aged 18 years and over registered to Welsh Demographic Service Dataset (WDSD), who were alive and resident in Wales as at 31st July 2022. Coverage of at least one dose of COVID-19 vaccination in the study population was generally high (92.4 %), suggesting that on the whole, the vaccination programme has been well received and delivered in Wales. The highest reported uptake was among those aged 80 years and over and among females. However, as previous studies have highlighted [3,4] significant inequities in coverage remain across several categories. This study has highlighted that some groups and individuals have potentially been under-served by the vaccination programme, some of whom may also have been at an already increased risk of severe outcomes to COVID-19. The poorest levels of uptake were found among those with a history of homelessness, those with substance misuse issues and those in the combined Black ethnic group, although, odds of vaccination in each of these groups improved slightly within the multivariable analysis suggesting other factors will be important to consider in improving uptake in these groups. Those born outside of the UK also saw reduced odds of being vaccinated but saw little difference between the univariable and multivariable analyses, suggesting this, or a related confounding factor such as missing vaccination documentation, is the main factor influencing uptake in this group.

4.2. Strengths and weaknesses

A major strength of this study is the nationwide approach to population-linked data. By combining a variety of data sources we were able to provide a representative picture of the eligible population for COVID-19 vaccination in Wales since the programme began in December 2020, and examine a wide range of person-level and sociodemographic characteristics relating to under-served groups.

Another strength of this study is the use of multivariable analysis, which afforded the ability to observe the simultaneous impact of a range of variables on vaccination uptake among various under-served groups and sociodemographic characteristics. This approach provided a more accurate representation of the interplay of factors associated with

Table 1
Distribution of study population and the general population, Wales; 31st July 2022[a].

Characteristic	Category	Study Population		General Population		X² P-value
		n	*%*	*n*	*%*	
Ethnic group	Combined White	1,390,003	92.7	2,050,215	84.7	0.72
	Combined Black	5,134	0.4	12,466	0.5	
	Combined Asian	25,010	1.7	47,113	1.9	
	Mixed	12,258	0.9	34,425	1.4	
	Other	3,824	0.3	10,923	0.5	
	Unknown	–	0.0	266,381	11.0	
Health Board of Residence	HB 1	277,062	19.3	454,927	18.8	0.77
	HB 2	261,830	18.2	350,850	14.5	
	HB 3	163,603	11.4	292,437	12.1	
	HB 4	207,944	14.5	396,605	16.4	
	HB 5	225,920	15.7	308,829	12.8	
	HB 6	272,097	18.9	520,160	21.5	
	HB 7	27,773	1.9	97,715	4.0	
Age Group	18–29	228,247	15.9	415,111	17.1	0.96
	30–39	208,046	14.5	430,892	17.8	
	40–49	202,217	14.1	361,436	14.9	
	50–59	259,118	18.0	415,612	17.2	
	60–69	234,317	16.3	358,827	14.8	
	70–79	196,611	13.7	283,397	11.7	
	80+	107,673	7.5	156,248	6.5	
Sex	Male	685,070	47.7	1,211,867	50.0	0.64
	Female	751,159	52.3	1,209,637	50.0	
	Unknown	–	0.0	19	0.0	
WIMD Domain: Physical Environment	Most deprived	275,904	19.2	508,308	21.0	0.99
	2	301,891	21.0	87,328	20.1	
	3	305,966	21.3	482,941	19.9	
	4	282,456	19.7	476,421	19.7	
	Least deprived	270,012	18.8	466,525	19.3	
WIMD Domain: Community Safety	Most deprived	266,476	18.6	489,897	20.2	1.00
	2	292,891	20.4	475,636	19.6	
	3	292,472	20.4	488,402	20.2	
	4	293,650	20.4	492,567	20.3	
	Least deprived	290,740	20.2	475,021	19.6	
WIMD Domain: Housing	Most deprived	240,607	16.8	486,131	20.1	0.95
	2	284,821	19.8	476,523	19.7	
	3	292,364	20.4	479,263	19.8	
	4	307,344	21.4	491,204	20.3	
	Least deprived	311,093	21.7	488,402	20.2	
WIMD Domain: Access to Services	Most deprived	246,858	17.2	476,043	19.7	0.97
	2	282,798	19.7	490,152	20.2	
	3	297,086	20.7	491,033	20.3	
	4	304,662	21.2	489,467	20.2	
	Least deprived	304,825	21.2	474,828	19.6	
WIMD Domain: Education	Most deprived	276,061	19.2	476,233	19.7	1.00
	2	282,787	19.7	485,611	20.1	
	3	289,681	20.2	487,098	20.1	
	4	294,522	20.5	490,551	20.3	
	Least deprived	293,178	20.4	482,030	19.9	
Q-COVID	0	551,181	38.4	1,060,314	43.8	0.81
Comorbidity	1	506,853	35.3	835,204	34.5	
Score	2	234,021	16.3	330,280	13.6	
	3	89,133	6.2	121,891	5.0	
	4	34,158	2.4	45,728	1.9	
	5	20,883	1.5	28,106	1.2	
Hearing loss	No	1,248,581	86.9	1,806,538	74.6	0.08
	Yes	187,648	13.1	241,245	10.0	
	Unknown	–	0.0	373,740	15.4	
Severe Mental	No	1,432,042	99.7	2,041,012	84.3	0.09
Illness	Yes	4,187	0.3	6,735	0.3	
	Unknown	–	0.0	373,776	15.4	
Substance	No	1,403,894	97.7	2,358,016	97.4	0.82
Misuse	Yes	32,335	2.3	63,507	2.6	
Homelessness	No	1,426,635	99.3	2,394,079	98.9	0.66
	Yes	9,594	0.7	27,444	1.1	
English/Welsh not first	No	1,390,689	96.8	1,833,012	75.7	**0.02**
language	Yes	45,540	3.2	75,085	3.1	
	Unknown	–	0.0	513,426	21.2	
Born Outside	No	1,375,685	95.8	1,789,807	73.9	**0.01**
UK	Yes	60,544	4.2	93,868	3.9	
	Unknown	–	0.0	537,848	22.2	
Physical	No	1,194,047	83.1	1,506,891	62.2	**0.01**
Disability	Yes - limited a little	135,026	9.4	133,681	5.5	
	Yes- limited a lot	107,156	7.5	169,396	7.0	

Table 1 (*continued*)

Characteristic	Category	Study Population		General Population		X² P-value
		n	*%*	*n*	*%*	
	Unknown	–	0.0	611,555	25.3	
Household	Partnership	405,255	28.2	648,454	26.8	0.98
Composition	Lone-dwelling	201,718	14.0	335,651	13.9	
	Family	361,403	25.2	602,094	24.9	
	Large Family	70,066	4.9	141,001	5.8	
	Adult Group, Single Generation	16,515	1.1	53,728	2.2	
	Adult Group, Multi-Generation	365,264	25.4	570,850	23.6	
	Large Adult Group, Single Generation	590	0.0	6,205	0.3	
	Large Adult Group, Multi-Generation	11,252	0.8	30,607	1.3	
	House Size 10+	4,166	0.3	32,933	1.4	

[a] To assign deprivation quintile, small area geography Lower-layer Super Output Area (LSOA) 2011 of residence were ranked by Welsh Index of Multiple Deprivation (WIMD) 2019 score and the populations divided into quintiles.

vaccination uptake in these groups and highlights the importance of not considering dimensions in isolation. For example, this study demonstrated that despite being associated with significantly lower odds of being vaccinated than the combined White ethnic group in the univariable analysis, those in the combined Asian ethnic group were found to have significantly higher uptake when other variables were considered.

The main limitation of this study was that we relied on the ONS 2011 census to ascertain uptake among those with a physical disability, meaning that only those living in Wales during the 2011 census are included in the study population due to a complete case analysis approach. This may impact the generalisability of the findings to the current population as it excludes those who moved to Wales since 2011. On comparison of the study population to the general population, a proportion of those born outside of the UK and living in the more deprived areas were disproportionately affected by this exclusion. This may mean the effect of some of these variables are underestimated in the multivariable analysis. Data were also restricted to the 31st July 2022, as this was the most recent update to the data available to indicate a history of substance misuse via the SMDS dataset. As the analysis is conducted within SAIL, findings are based on the data of the 86 % of primary care practices that submit data to SAIL, however, this is unlikely to bias results as practices who do not contribute to SAIL are geographically distributed and serve similar populations.

As the flag indicating substance use is based on records since 2014, it reflects both historic and present substance use problems and therefore those included may be in recovery at the time of vaccination.

Distance to the nearest Mass Vaccination Centre did not appear to be associated with uptake of vaccination, which was not surprising given the very small differences in distances between the vaccinated and unvaccinated groups. In addition, very weak discrimination between vaccination groups based on distance meant using the raw measure of distance was problematic for achieving model convergence. The inclusion of distance was based on the assumption of a linear relationship between distance and vaccine uptake but this may not be appropriate and further work is needed to understand this relationship for modelling effects at a population level. Universal invitations to attend for vaccinations were used for those with a registered address or registered mobile telephone number and Mass Vaccination Centres were promoted via local communication campaigns and signposted on-site. However, it is possible that awareness of locations was not uniform across all population groups, and other accessibility features such as convenience of appointment times and opening hours may have influenced the feasibility of attendance at these centres.

Finally, as with all study designs which utilise administrative data for secondary uses, there is a possibility of miscoding and inaccurate records leading to an underestimation of effect size. There is also the potential for further individuals from hidden populations to be missed as they have not engaged with any of the services that data were sourced from, likely underestimating the strength of findings in this study. There are particular challenges in defining ethnic groups and asylum seekers and refugees from routine administrative data sources, creating challenges to ensuring equitable vaccination uptake among these groups given the lack of coding in routine data sources [26]. However, country of birth and date of arrival may be a useful proxy for asylum seekers and refugees if coded accurately. For example, in this population (data not presented), coverage of one dose of vaccination in those recorded as born in Ukraine and arriving during 2022 was 18 %.

4.3. Context of other literature

This research adds to the existing literature highlighting poorer levels of uptake among those with a history of homelessness [8,11] and those with severe mental illness [9,10]. However, a recent cohort study in England found vaccination rates were higher among those with severe mental illness after controlling for sociodemographic covariates, including age, sex, deprivation and ethnicity [27], suggesting other variables included in this study may contribute to poorer uptake in this group. Poor vaccination coverage in these groups is troubling given their increased risk of severe outcomes from COVID-19 [5–7,28–33]. There is significant overlap between homelessness, substance misuse and severe mental illness [12], and given the high levels of comorbidity and their association with other socioeconomic factors, both vulnerability and inequality are likely to be additive and compounding [34]. Health-seeking behaviour is also likely influenced by mental disorders, and it is likely that uptake varied by specific disorders [35].

Asylum Seekers and Refugees are a particularly vulnerable group who are likely to have experienced recent unstable living conditions [36,37]. Although we were unable to specifically identify this population for the purpose of this study, this research found coverage of one dose of COVID-19 vaccine in those who were born outside the UK or whose first language was not English or Welsh was lower. This has been observed with childhood immunisations in Wales [38] and elsewhere for COVID-19 vaccination in adults [10,39,40].

Aligning with similar research in England [10], this study has shown that those with physical disabilities are less likely to be vaccinated after controlling for other factors compared to those without. Although the gap in uptake was more pronounced in this study. Reassuringly, coverage in those with sensory disability appears to be above that of the general population in this study.

4.4. Implications for policy and practice

Data capture on a number of under-served groups associated with lower uptake in this research is often poor. Those with a history of homelessness, substance use, severe mental illness and asylum seekers and refugees are often 'invisible' to routine surveillance and thus establishing accurate estimations of vaccination uptake in these groups

Table 2

Uptake of one dose of COVID-19 vaccine (any type) and odds of being vaccinated, Wales; 31st July 2022[a,b,c].

Characteristic	Category	Population (n)	Uptake (%)	Univariable		Multivariable	
				OR	95 % CI	OR	95 % CI
Ethnic group	Combined White	1,390,003	92.7	Ref.		Ref.	
	Combined Black	5,134	75.7	0.25	(0.23–0.26)	0.66	(0.62–0.71)
	Combined Asian	25,010	89.2	0.65	(0.63–0.68)	1.68	(1.61–1.76)
	Mixed	12,258	80.6	0.33	(0.31–0.34)	0.54	(0.51–0.57)
	Other	3,824	79.7	0.31	(0.29–0.34)	0.83	(0.76–0.90)
Health Board of Residence	HB 1	277,062	92.6	Ref.		Ref.	
	HB 2	261,830	93.0	1.06	(1.04–1.08)	1.18	(1.16–1.21)
	HB 3	163,603	92.3	0.96	(0.94–0.99)	0.94	(0.92–0.96)
	HB 4	207,944	91.4	0.85	(0.83–0.87)	0.91	(0.89–0.93)
	HB 5	225,920	91.8	0.90	(0.88–0.92)	0.96	(0.94–0.99)
	HB 6	272,097	92.8	1.03	(1.01–1.05)	1.19	(1.16–1.22)
	HB 7	27,773	93.2	1.09	(1.04–1.14)	1.02	(0.97–1.07)
Age Group	18–29	228,247	85.4	0.32	(0.31–0.33)	0.33	(0.32–0.34)
	30–39	208,046	85.3	0.32	(0.31–0.33)	0.34	(0.33–0.35)
	40–49	202,217	90.8	0.54	(0.53–0.55)	0.60	(0.59–0.61)
	50–59	259,118	94.8	Ref.		Ref.	
	60–69	234,317	96.7	1.60	(1.55–1.64)	1.53	(1.49–1.58)
	70–79	196,611	98.0	2.65	(2.56–2.75)	2.47	(2.38–2.56)
	80+	107,673	98.5	3.69	(3.50–3.89)	3.52	(3.33–3.71)
Sex	Male	685,070	91.2	Ref.		Ref.	
	Female	751,159	93.5	1.38	(1.36–1.40)	1.32	(1.31–1.34)
WIMD Domain: Physical Environment	Most deprived	275,904	91.6	Ref.		Ref.	
	2	301,891	92.4	1.12	(1.10–1.14)	0.98	(0.96–1.00)
	3	305,966	92.6	1.15	(1.13–1.17)	0.97	(0.95–0.99)
	4	282,456	92.7	1.18	(1.15–1.20)	0.95	(0.93–0.98)
	Least deprived	270,012	92.7	1.16	(1.14–1.19)	0.96	(0.93–0.98)
WIMD Domain: Community Safety	Most deprived	266,476	89.3	Ref.		Ref.	
	2	292,891	91.5	1.29	(1.27–1.32)	1.11	(1.08–1.13)
	3	292,472	92.6	1.50	(1.47–1.53)	1.12	(1.09–1.14)
	4	293,650	93.5	1.72	(1.68–1.75)	1.15	(1.12–1.18)
	Least deprived	290,740	94.7	2.16	(2.11–2.20)	1.19	(1.16–1.23)
WIMD Domain: Housing	Most deprived	240,607	90.5	Ref.		Ref.	
	2	284,821	91.5	1.13	(1.11–1.15)	1.07	(1.05–1.09)
	3	292,364	91.9	1.19	(1.17–1.21)	1.09	(1.07–1.12)
	4	307,344	92.9	1.37	(1.35–1.40)	1.10	(1.07–1.12)
	Least deprived	311,093	94.6	1.86	(1.82–1.89)	1.13	(1.10–1.16)
WIMD Domain: Access to Services	Most deprived	246,858	92.4	Ref.		Ref.	
	2	282,798	90.3	0.76	(0.75–0.78)	1.01	(0.99–1.04)
	3	297,086	91.8	0.92	(0.91–0.94)	1.07	(1.04–1.09)
	4	304,662	93.1	1.10	(1.08–1.13)	1.12	(1.10–1.15)
	Least deprived	304,825	94.3	1.35	(1.32–1.38)	1.15	(1.12–1.18)
WIMD Domain: Education	Most deprived	276,061	88.5	Ref.		Ref.	
	2	282,787	91.3	1.35	(1.33–1.38)	1.16	(1.13–1.18)
	3	289,681	92.8	1.66	(1.63–1.69)	1.28	(1.25–1.31)
	4	294,522	94.0	2.03	(2.00–2.07)	1.48	(1.44–1.51)
	Least deprived	293,178	95.1	2.52	(2.47–2.57)	1.68	(1.64–1.73)
Q-COVID Comorbidity Score	0	551,181	91.2	Ref.		Ref.	
	1	506,853	92.1	1.13	(1.12–1.15)	1.05	(1.04–1.07)
	2	234,021	93.6	1.40	(1.38–1.43)	1.21	(1.18–1.23)
	3	89,133	95.3	1.96	(1.90–2.03)	1.44	(1.39–1.49)
	4	34,158	96.4	2.62	(2.47–2.78)	1.65	(1.55–1.76)
	5	20,883	97.8	4.32	(3.94–4.75)	2.10	(1.91–2.32)
Hearing loss	No	1,248,581	92.0	Ref.		Ref.	
	Yes	187,648	95.1	1.69	(1.65–1.72)	1.20	(1.17–1.23)
Severe Mental Illness	No	1,432,042	92.4	Ref.		Ref.	
	Yes	4,187	86.1	0.51	(0.47–0.55)	0.64	(0.59–0.71)
Substance Misuse	No	1,403,894	92.8	Ref.		Ref.	
	Yes	32,335	76.3	0.25	(0.24–0.26)	0.45	(0.44–0.46)
Homelessness	No	1,426,635	92.5	Ref.		Ref.	
	Yes	9,594	70.6	0.19	(0.19–0.20)	0.58	(0.55–0.61)
English/Welsh not first language	No	1,390,689	92.6	Ref.		Ref.	
	Yes	45,540	85.8	0.48	(0.47–0.49)	0.78	(0.75–0.81)
Born Outside UK	No	1,375,685	92.8	Ref.		Ref.	
	Yes	60,544	84.2	0.42	(0.41–0.43)	0.44	(0.43–0.46)
Physical Disability	No	1,194,047	92.1	Ref.		Ref.	
	Yes - limited a little	135,026	94.1	1.38	(1.34–1.41)	0.75	(0.73–0.77)
	Yes- limited a lot	107,156	93.4	1.21	(1.18–1.24)	0.63	(0.62–0.65)
Household Composition	Partnership	405,255	95.7	Ref.		Ref.	
	Lone-dwelling	201,718	93.6	0.67	(0.65–0.68)	0.69	(0.67–0.70)
	Family	361,403	90.0	0.41	(0.40–0.42)	0.90	(0.88–0.92)
	Large Family	70,066	83.9	0.24	(0.23–0.24)	0.58	(0.56–0.59)
	Adult Group, Single Generation	16,515	85.9	0.28	(0.26–0.29)	0.62	(0.59–0.66)
	Adult Group, Multi-Generation	365,264	92.8	0.58	(0.57–0.59)	1.00	(0.98–1.02)

Table 2 (*continued*)

Characteristic	Category	Population (n)	Uptake (%)	Univariable		Multivariable	
				OR	95 % CI	OR	95 % CI
	Large Adult Group, Single Generation	590	78.8	0.17	(0.14–0.21)	0.66	(0.54–0.81)
	Large Adult Group, Multi-Generation	11,252	85.7	0.27	(0.26–0.29)	0.66	(0.62–0.70)
	House Size 10+	4,166	76.8	0.15	(0.14–0.16)	0.38	(0.35–0.41)

[a] Data sourced from CVVD as at 31th July 2022.
[b] Multivariable regression model estimates adjusted for all other variables listed in the table.
[c] To assign deprivation quintile, small area geography Lower-layer Super Output Area (LSOA) 2011 of residence were ranked by Welsh Index of Multiple Deprivation (WIMD) 2019 score and the populations divided into quintiles.

is challenging. While this study goes someway to estimating uptake in this populations, improved flags in routine datasets to identify these populations will help to improve our understanding of coverage and target interventions.

Improving outreach services using established and trusted services, organisations and advocates are a common theme suggested for improving uptake among those with a history of homelessness [41–43], substance misuse [33] and severe mental illness [29,30,34,44]. Utilising existing, trusted relationships to facilitate productive discussions about vaccination alongside co-production of information and outreach materials and are likely to improve uptake among a variety of under-served groups discussed in this study [45,46]. Similarly, offering alternative locations and flexible appointments for vaccination may also help improve uptake, such as offering vaccination within existing support services and aligning COVID-19 vaccination with other vaccinations [33,34].

Previous interactions with healthcare services can leave those with severe mental illness [47] and substance misuse problems [48] feeling stigmatised by healthcare professionals and are less likely to engage with healthcare services, including vaccination and screening campaigns [49,50]. This coupled with vaccine hesitancy observed in previous studies [27,33] is problematic for improving uptake in these groups. Improved engagement work with communities and education among vaccine providers of challenges faced by under-served groups are key, alongside improving access and availability of services to make it easier to administer vaccinations may help improve uptake [49,51].

Those with physical disabilities face a number of challenges to vaccination, including travel, access to information and booking appointments, as well as a lack of understanding of physical disabilities by vaccination centre staff [52]. Given the lower levels of uptake in this group reported in this study, uptake may be improved through better understanding of physical disabilities among staff administering vaccinations and improving accessibility to both booking vaccinations and at vaccination centres themselves.

Given the difficulties identifying asylum seekers and refugees in routine data sources, being able to develop interventions focused on language requirements or guidance on recording immunisations from certain countries may be more beneficial for service. Ensuring those who arrive in Wales have the information they need regarding health services in induction packs in accessible formats and are aware they are eligible for free vaccination should be a priority.

The finding that those in the Asian ethnic group were more likely to be vaccinated compared to those in the White ethnic group after controlling for other factors aligns with previous research examining measles vaccination uptake in Wales [38], but is nevertheless a surprising finding given research in the UK has highlighted an increased likelihood of vaccine hesitancy among those from Asian ethnic groups compared to those from White ethnic groups [53]. Positive attitudes towards government, public officials and healthcare professionals as well as addressing vaccine misinformation through engaging community leaders have been highlighted as important agents in improving uptake in ethnic minority groups [53].

Lastly, it is also important to consider that while some groups may not have significantly poorer uptake compared to others, under-

vaccination in some groups in this cohort is especially significant given their increased susceptibility to severe outcomes from COVID-19.

The findings in this study will support work by the Wales Vaccine Equity Network to promote equitable access to vaccination, using a data-driven and participatory approach with representatives from organisations that support under-served groups alongside representatives from Welsh Government, Public Health Wales and NHS Wales vaccination delivery teams [54].

4.5. Further research

The current study focuses on the uptake of the first vaccination dose only, and as previously published data [2] has highlighted that uptake of subsequent doses has generally been lower overall, future research may therefore benefit from expanding to look at additional doses of COVID-19 vaccination.

This study has estimated vaccination uptake for a number of previously unknown groups and there is scope to apply similar methods to evaluate coverage across other vaccination programmes or areas of health care (for example, screening services). Whilst this study expands the evidence base on inequalities in coverage, it is not possible to fully understand the under-lying root-causes of immunisation inequities through a purely quantitative approach. Further qualitative research with the communities directly affected is essential to examine the multiple and overlapping risk factors identified, identify the actual barriers to uptake and co-produce effective interventions to improve uptake. This is particularly pertinent for those under-served groups we know have significant comorbidities such as homelessness, substance misuse and severe mental illness.

5. Conclusion

In conclusion, Wales saw high levels of coverage of at least one dose of COVID-19 vaccination. However, there were significant inequalities in the uptake in a number of under-served populations. This is particularly concerning given these populations are often at an elevated risk of severe outcomes from COVID-19 infection. Ensuring equitable access to vaccination is an essential starting point to protecting the health of these populations, however, tailoring of vaccination pathways and advocacy in some groups will be essential in addressing these gaps in coverage.

Declaration of Competing Interest

Data availability

The data used in this study are available in the SAIL Databank at Swansea University. All proposals to use SAIL data are subject to review by an independent Information Governance Review Panel.

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