SPI-B: Behavioural considerations for vaccine uptake in Phase 2 and beyond

Date: 09 March 2021, v2

1. This document is a rapid evidence analysis, based on the latest available data prepared by the University of Oxford on behalf of SPI-B. It was presented at the March 09 2021 SPI-B meeting and signed off by chairs on behalf of the committee.

Executive Summary

2. The aim was to provide behaviourally-informed evidence to ensure equitable access and effective delivery for Phase 2 vaccine uptake. Given scant and timely literature on COVID-19 vaccinations and behaviour,[1,2] we undertook new primary analyses with the aim to: (1) describe vaccine uptake by disaggregated stratified groups, (2) understand recent motivations of vaccine hesitancy by more stratified groups and nuanced understanding, (3) understand adherence to non-pharmaceutical interventions (NPIs) in the general population, by those who have been vaccinated and by differences by first or second dose, (4) understand the relationship of adherence to infections; and, (5) advise on how this evidence may guide public messaging and operational delivery. To increase transparency, details of analyses are included (Appendices 1-2) and the quality of the evidence and strength of recommendations is scored according to the standard GRADE system (Appendix 3).
3. There is substantial variation in vaccine uptake as of 24 February 2021 by key sociodemographic factors. Results suggests it is important to move beyond broad categories, such as age or ethnicity, to examine the intersectional and cumulative effects of low vaccine uptake. There is cumulative low uptake compounded in certain groups such as those who are shielding and from deprived socioeconomic circumstances and also from non-White groups. **[high confidence]**
4. Examining ONS survey data from 10-24 February 2021 (N=12,109), vaccine hesitancy was the highest amongst non-Asian BAME (particularly Black) individuals and is lower within younger age groups. Individuals who are more compliant in following NPIs (avoid physical contact, wear a face covering), and who are more likely to support mass testing and lockdowns are significantly less likely to be vaccine hesitant. **[high confidence]**
5. Those less likely or able to comply with NPIs are 16-29 year olds, employed, from larger households, do not support the lockdown and oppose mass testing. We see a striking reduction in following NPI behavioural interventions over the three week period from February 10 to 24 2021. **[high confidence]**
6. Examining the same data, of which around 40% have been vaccinated with at least one dose, there is no statistically significant drop when we combine all types of NPI compliance after vaccination (e.g., having indoor gatherings >6, meeting up, not physical distancing, not washing hands when return home, not using face covering outside). **[medium confidence** *due to aggregated NPI variable which hides variation***]**
7. When we examine different types of NPIs, however, we see that those who have been vaccinated do not change adherence to measures with the exception of being significantly *more* likely to have worn face covering in the past 7 days. We also see nuances in non-compliance across different NPIs and groups. Younger people are less likely to adhere to social distancing, physical contact and hand hygiene, but more likely to wear a face covering (compared to those 70+). The BAME group in this period are more likely to adhere to meeting fewer people indoors and hand washing but those from larger households are less likely to adhere to rules related to

indoor social gatherings and hand washing. Opposition to the second lockdown means less adherence across all NPIs. **[high confidence]**

8. From a new ONS survey (N= 2,070) of the over 80's that have had at least one dose in the last 3 weeks, 67% had left home, 69% met indoors with someone outside of their household, 41% had met indoors with someone outside of their household, support bubble or personal care and 44% met with someone outdoors since being vaccinated. This suggests communications should focus on explaining the duration of immunity within the first 3 weeks after vaccination of the first dose. **[medium to high confidence]**
9. Using cell phone mobility data for 10% of the British population, linked to vaccination centres for February 2021, and difference-in-difference modelling that mimics a randomised control trial, we find that vaccinated users increase their mobility range compared to pre-vaccination mobility. It is only by a modest amount (218 metres) for the entire population, suggesting nearby contacts or visits. Supporting the Pareto principle, we find that although 79% of the vaccinated have limited mobility changes, 21% who were already highly mobile, increased their mobility even more by around 12.4% after vaccination. **[medium to high confidence].**
10. Modelling positive tests (N=409,009) nested in households (N=72,866) for individuals aged 18-64 from May 2020 to February 2021, we find that the level of autonomy in the ability to comply with COVID-19 behavioural measures (e.g., ability to maintain physical distancing at work, work at home, avoid public transport) does not alone predict testing positive for COVID-19. Rather, autonomy has a large and statistically significant effect on positive infections only when people do not wear a face covering or mask, suggesting that face coverings can mitigate the unequal effects of exposure to COVID-19. **[high confidence]**
11. The changing nature of COVID-19 related policy interventions from early 2020 until March 2021 means that different predictors have been more relevant across time, suggested a more nuanced and tailored approach to understanding the impact of interventions across various groups. For instance, autonomy to follow NPIs was more relevant in earlier periods and household size (particularly for women) in later periods. The impact of wearing a face covering or mask predicts a lower chance of infection across all periods. **[high confidence** May to December 20, 2020, **medium** (for later period December 20, 2020 – February 2021 due to smaller sample)**].**
12. Amplifying previous SPI-B recommendations on communications with more explicit empirical evidence relevant to COVID-19 we propose: (1) a more data-driven approach using transparent modelling of timely and nuanced disaggregated data, (2) move beyond broad sledgehammer categories of age and ethnicity to nuanced sub-groups that properly control for confounders and recognise intersectionality of stratified traits that result in cumulative disadvantage in order to be more effective and avoid stigmatising groups, (3) focus on the timeline over which immunity develops, particularly after the first dose, (4) continue messaging about positive effects of behavioural interventions such as face coverings, high vaccine uptake, low vaccine hesitancy, hope and return to longer goals and avoid blame or enforcement, (5) breakdown practical operational barriers to match the everyday lived experiences of individuals (large households, need to take public transportation, difficulties of maintaining physical proximity at certain workplaces).

Data and modelling of results

1. Data are described in Appendix 1, detailed methods and results in Appendix 2 and strengths and limitations assessed against GRADE standards in Appendix 3. Modelling includes: descriptive statistics, multivariate regression modelling of vaccine uptake, hesitancy, NPI compliance and infections in addition to difference-in-difference econometric modelling of pre- and post-vaccination mobility using cell phone data.
2. Six data sources are used to inform our behavioural-informed modelling: (1) OPENSafely COVID vaccine coverage, data, (N=23.4 Million, N=6,454,259 vaccinated), (2) COVID Infection Survey (CIS) (N=409,009 nested in (N=72,866 households) (3) ONS Opinions and Lifestyle Survey, 3 waves from February 10, 17 and 24 2021 (aggregated N=12,758), (4) Mobile phone location data, 01-28 February 2021 (N=18.3 million individuals) , linked to (5) vaccination centre data on 19 February and; (6) Over 80s Vaccine Study, 15-20 February 2021 (N=2,070).

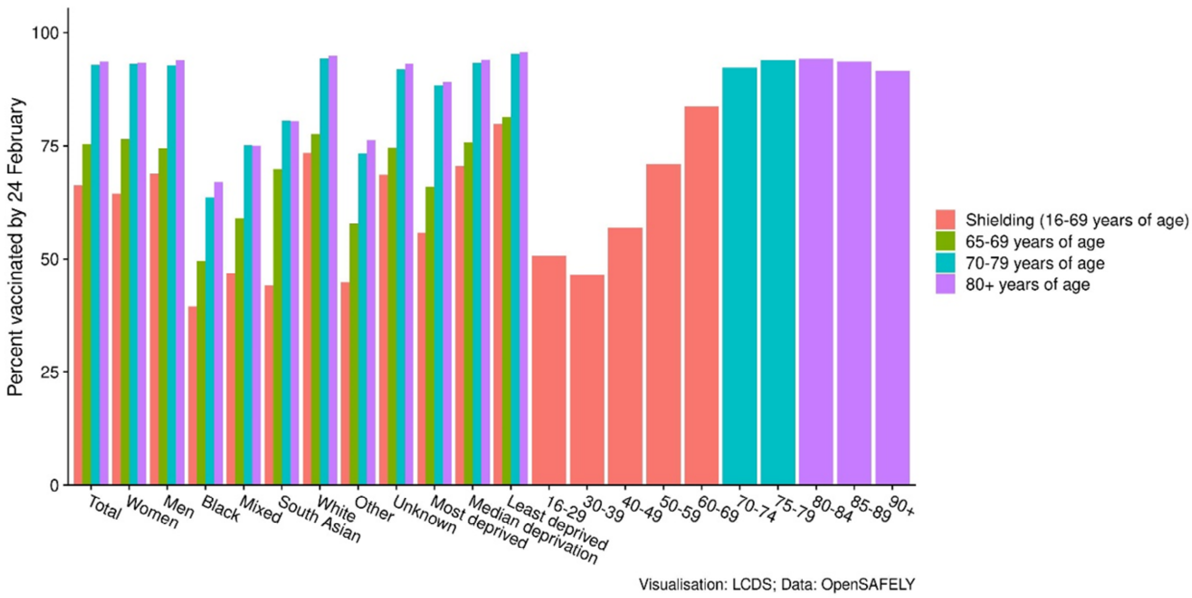
Understanding Motivations: Vaccine uptake and hesitancy

Vaccine uptake

3. Examining the uptake of the first JCVI priority groups of those 65 years of age and older, in care homes, shielding and under 65s not in these groups (e.g., health care workers) as of 24 February 2021, Figure 1 shows that although there is very high uptake in the oldest age groups, we see substantial variation by key sociodemographic factors in England. There is substantially lower uptake in the shielding group for those under 49 years. Amongst ethnic groups, supporting previous SAGE ethnicity sub-group work on this topic,[3] we see that compared to 'White' there is low uptake amongst Black, followed by Mixed and Other ethnic groups, and then South Asian groups.[i] This suggests a more disaggregated examination of ethnicity beyond broad BAME (Black, Asian and Minority Ethnic) categorisation may capture relevant mixed and other ethnic categories and disadvantaged groups (e.g., Gypsy, Roma Travellers, mixed, Eastern European groups).
4. In addition to age and ethnicity, there are socioeconomic gradients, with those in the most deprived circumstances having the lowest uptake. To efficiently target low uptake in a more tailored manner, results suggest a need to move beyond broad groups of age or ethnicity, towards intersectionality (combined categories). We see that there are cumulative effects of low vaccine uptake for those who are shielding but also from deprived socioeconomic circumstances and also from all non-White groups. The low uptake amongst young clinically vulnerable individuals is not novel to the COVID-19 vaccine and is also seen with the seasonal influenza vaccinations.

[i] The detailed composition of all ethnicity categories is included on OPENSafely's GitHub site.[24] Mixed includes categories such as Black and Chinese, Black Caribbean and White, Black African and White, White and Asian and many other detailed groups. Other includes a mix such as Chinese, Japanese, Korean, Fijian, Iranian, Latin American, and Moroccan.

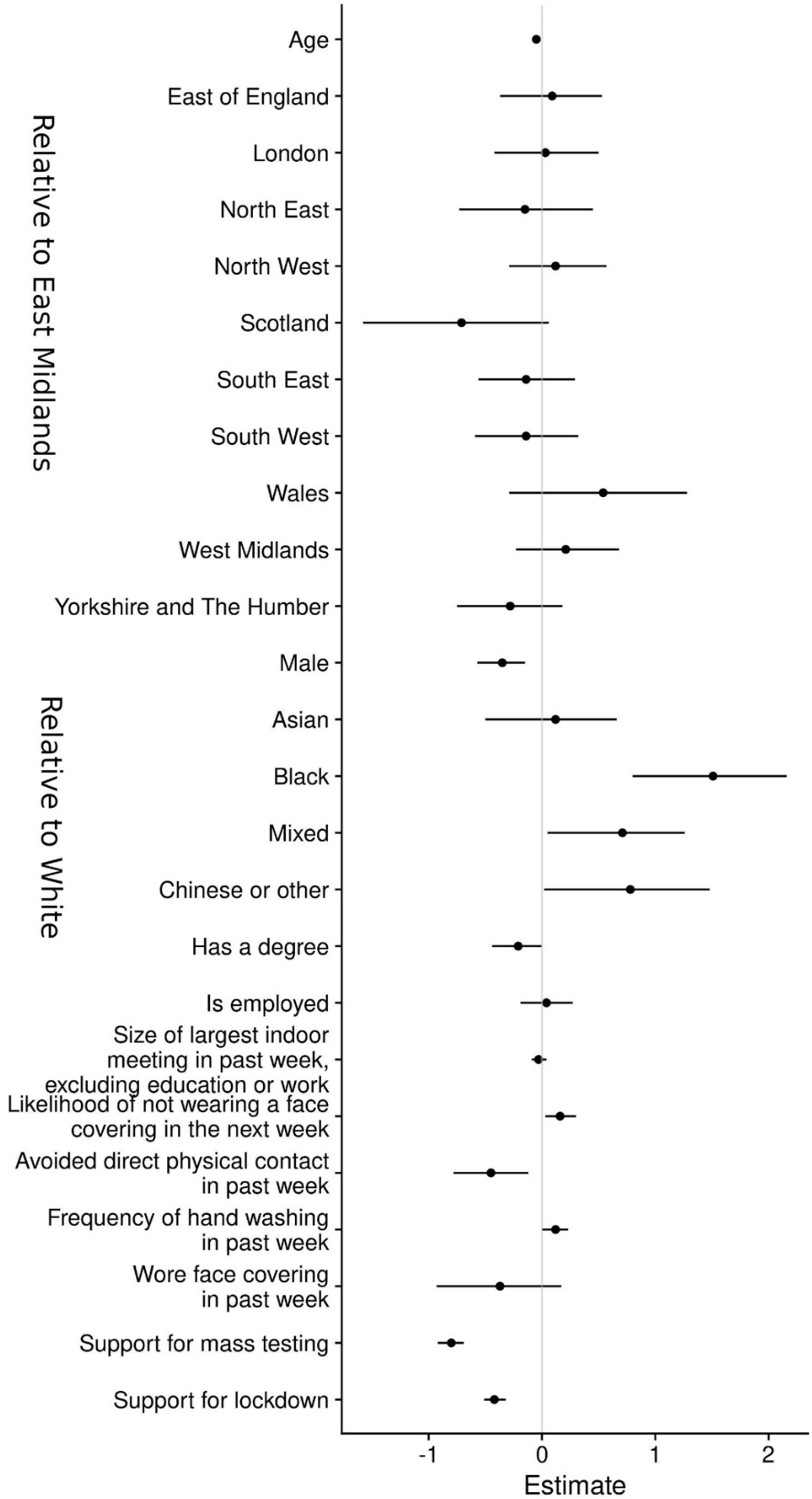
Figure 1. Percentage vaccinated by age and shielding group stratified by sex, ethnicity, social deprivation and JCVI age bands, England, 24 February 2021



Vaccine hesitancy

5. A concern for Phase 2 vaccine roll out is vaccine hesitancy, which is a delay in vaccine acceptance, or refusal despite availability,[4,5] which could compromise equitable access and effective delivery. A review described the 5 C's underlying COVID-19 vaccine hesitancy[1] which are: Confidence (safety, effectiveness of vaccines, side effects, ingredients, testing on certain groups), Complacency (personal perception of risk, severity of disease), Convenience (practical barriers, access), Context (understanding social, cultural and demographic context, mistrust) and Communications (sources of information, reliability of information, trust).
6. Pooling three waves (weeks of 10, 17 and 24 February 2021) from the ONS Opinions and Lifestyle Survey (N=12,109), we modelled known behavioural and sociodemographic predictors of vaccine hesitancy, but also added novel COVID-19 relevant variables such as support for lockdown and mass testing and compliance to various NPI regulations (indoor meetings, wearing a face covering, avoiding direct physical contact, hand washing). Vaccine hesitancy was coded as binary variable with 11,885 not hesitant and 639 as hesitant.
7. Vaccine hesitancy is highest amongst non-Asian BAME and particularly Black individuals and decreases modestly with age. Hesitancy is negatively correlated with behavioural adherence to various NPIs (Figure 2). In particular, individuals who are more likely to avoid direct physical contact in the last week and wear a face covering in the past week, more likely to support mass testing and lockdowns are significantly less likely to be vaccine hesitant. Although results show differences by geography (lower in Scotland, higher in Wales, relative to the East Midlands), this is dependent on adjustment by various socio-demographic, economic and behavioural variables and requires further scrutiny.

Figure 2. Bayesian logistic regression parameter estimates of vaccine hesitancy, 10-24 February 2021, Great Britain



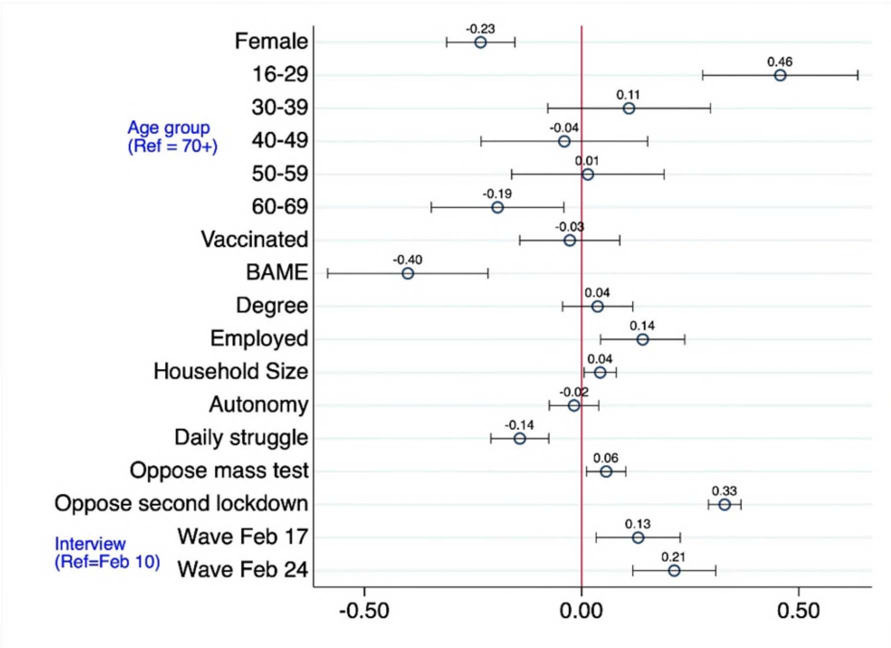
Adherence to NPIs following vaccination

8. A December 2020 SPI-B report noted a lack of evidence examining changes of behaviour due to vaccination roll out, but was able to report indirect evidence from surveys and previous vaccination campaigns, suggesting that those who are vaccinated may reduce personal protective behaviours.[2] We are now able to provide more explicit empirical and data-driven evidence by conducting primary analyses using multiple data sources from large survey data to mobile phone mobility data.

Adherence to NPIs in the general population

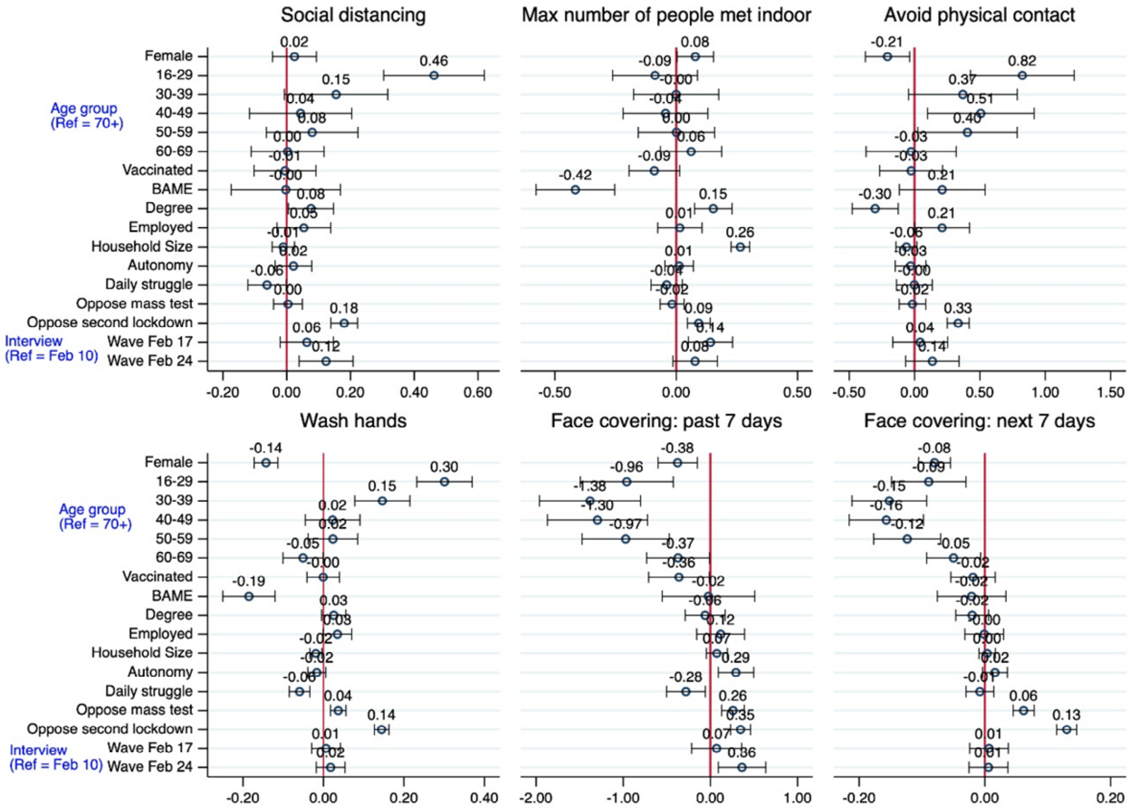
9. We first pooled three waves of data collected in the weeks of 10, 17 and 24 February 2021 from the ONS Opinions and Lifestyle Survey, for individuals aged 16 and over (N=12,109). Our outcome variable is a count of individuals' adherence to various NPIs over the last 7 days, which included measures such as having indoor and outdoor gatherings >6, meeting up with people, not physical distancing, not washing hands when returning home or not using a face covering when outside (see Appendix 2). Around 40% of the people in our data have had at least one dose of the vaccine. We find no statistically significant difference in following behavioural NPIs in our broad aggregated measure between those who were vaccinated versus those who have not. As we noted in the previous vaccine hesitancy analysis there is, however, considerable variation between NPIs and our broad count measure may thus conceal particular effects and important variations in NPIs, which will we explore in later detailed analyses.
10. Groups less likely or able to comply to NPIs are aged 16-29 years, employed, and from larger households (Figure 3). Those who do not support the current lockdown and oppose mass testing are strongly and significantly less likely to adhere to NPIs. We see an increase in non-compliance to NPIs over the three week period, with an increase in non-compliance growing over time until the end of February. We note that further analyses will explore confounding by omitted or unobserved variables and variation within NPIs.

Figure 3. Poisson regression estimates of non-adherence to NPIs, age 16 and over, 10-24 February 2021



13. When we examine different types of NPIs, however, we see that those who have been vaccinated do not change adherence to NPIs with the exception of being significantly *more likely* to have worn face covering in the past 7 days (Figure 4). Here we provide evidence this it is important to look at differences across NPIs and nuances in non-compliance by NPI and stratified groups. Younger people are less likely to adhere to social distancing, physical contact and hand hygiene, but more likely to wear a face covering (compared to those 70+). The BAME group in this period are more likely to adhere to meeting fewer people indoors and hand washing but those from larger households are less likely to adhere to rules related to indoor social gatherings and hand washing. Opposition to the second lockdown means less adherence across all NPIs.

Figure 4. Regression estimates of *non-adherence* to NPIs, age 16 and over, 10-24 February 2021

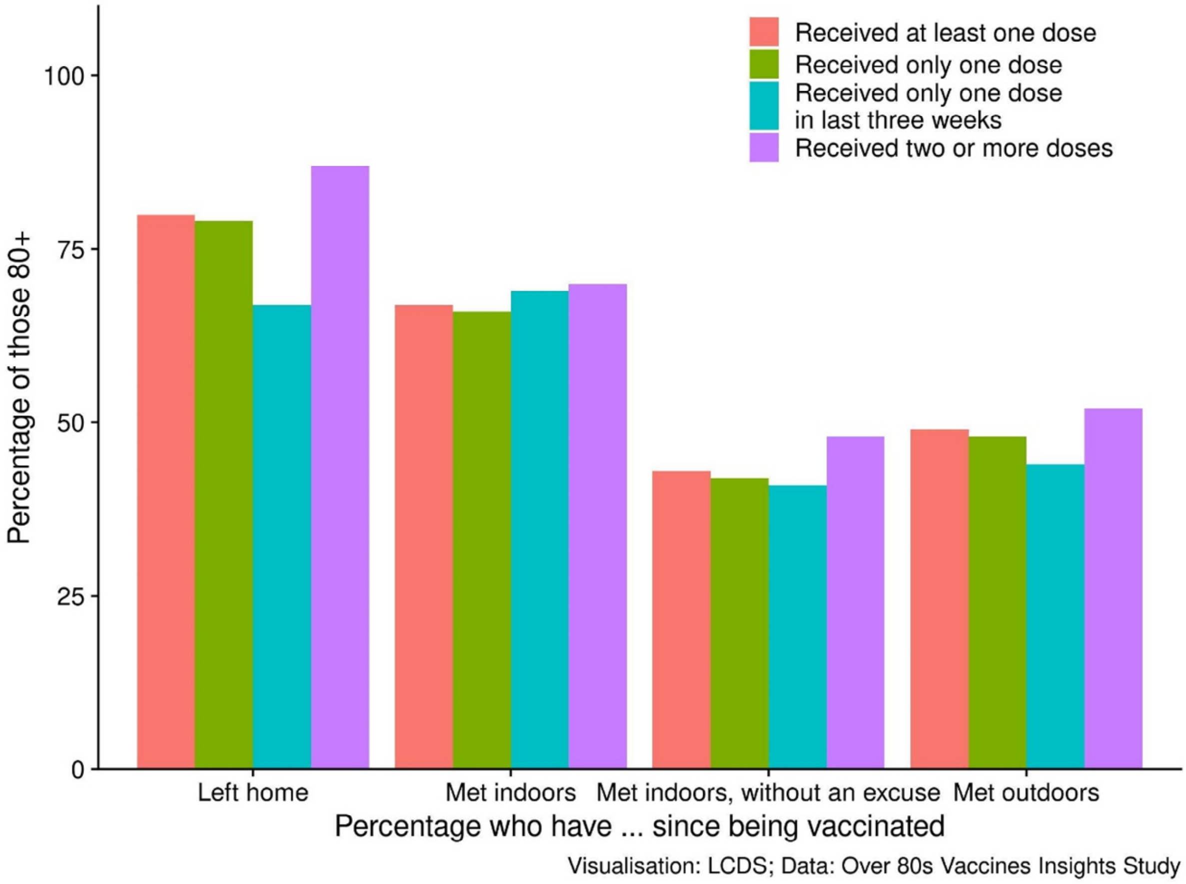


Adherence in the over 80s and differences by doses

11. By mid-February 2021, of the 2,830,000 over 80s population in England, 99.8% had been offered the COVID-19 vaccine and 84% had received one dose and 15% more than one dose. Using data from the experimental ONS Over 80s survey of a representative population in that group (N=2,070), we gain preliminary insights into compliance to behavioural regulations after receiving one or two doses of the vaccine in a group that is highly vulnerable to COVID-19 severe illness and death.[6]
12. Figure 5 illustrates that in the over 80's group that has had at least one dose in the last 3 weeks, 67% had left home, 69% met indoors with someone outside of their household, 41% had met indoors with someone outside of their household, support bubble or personal care and 44% met with someone outdoors since being vaccinated. The reasons for those who are over 80 for leaving the home is shown in Appendix 2, which is primarily for medical reasons, followed by

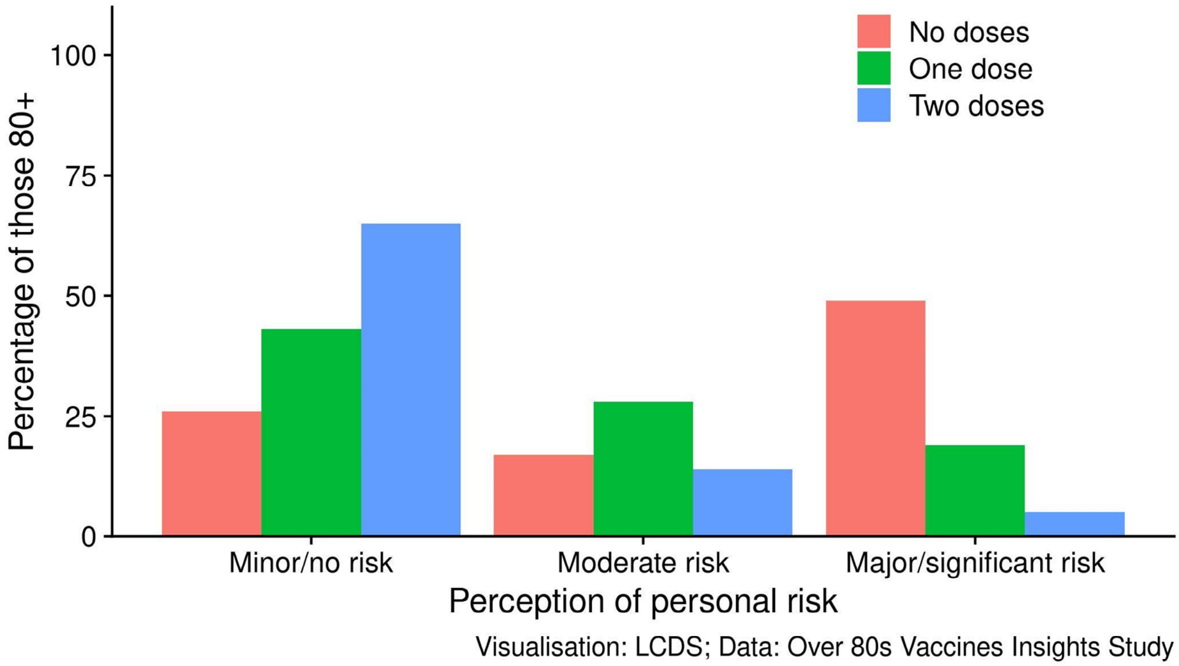
going to the shops or outdoor recreation. This suggests communications may need to focus on explaining the duration of immunity within the first 3 weeks after receipt of the first dose. We note a caveat that this age group is likely to have more interaction with others outside of the household for caring duties, but also note that when they do leave the household it is often for medical appointments (see Appendix).

Figure 5. Adherence to guidance since receiving at least one dose of the vaccine, over 80s, 15-20 February 2021



13. Perceptions of personal risk differ in relation to vaccination status from no vaccination to one or two doses (Figure 6). Perceptions of personal risk are lower after two doses, suggesting that in the over 80s there is an understanding that protection increases with the number of doses. This is in line with previous research,[1,2] including a systematic review of adherence to emergency public health measures, which found that perceived risk and perceived seriousness were significantly associated with either behavioural adherence or adherence intentions.[7]

Figure 6. Perception of personal risk of COVID-10 by doses of the vaccine, over 80s, 15-20 February 2021



Adherence to movement restrictions after vaccination using mobile phone mobility data

14. To provide additional evidence beyond self-reporting, we examined pre- and post-vaccination mobility data in the month of February 2021, using cell phone mobility data linked to vaccination centres of around 10% of phone users in Britain that was fully GDPR compliant and anonymised (see Appendix for data description). We find that vaccinated users increase their mobility range after being vaccinated (i.e., via monitoring mobile phones that visited vaccination centre). For the 4,254 users for whom we identified a vaccination event, their range of mobility, as measured by the radius of gyration, increased by 8.6% in the week after vaccination compared to the week before (Figure 7). Their average pre-vaccination mobility increased by 218 meters (from 2,529 to 2,759 meters). The difference is statistically significant, with the *p*-value of the Wilcoxon signed-rank test at 0.000.
15. The Pareto principle, which is a principle that for many outcomes, around 80% of the consequences come from 20% of the 'vital few', applies to compliance with lockdowns after vaccination.[8] 20% of high mobility individuals accounted for 79% of total increased mobility following vaccination (Figure 8). The 80% low mobility individuals who were vaccinated only increased mobility marginally by 82 meters or 5.4%. The corresponding 20% of high mobility users increased their mobility by 823 meters or 12.4%. A minority of vaccinated users increased their mobility by moderate amounts after their vaccination. The increases are modest in comparison to the impact of the 2021 lockdowns which reduced mobility in England by around 60%. This analysis suggests the possibility of closer social contacts both within and outside of the home or visits to nearby locations.

Figure 7. Change in mobility measure before and after the vaccination day (in meters), mobile phone mobility data

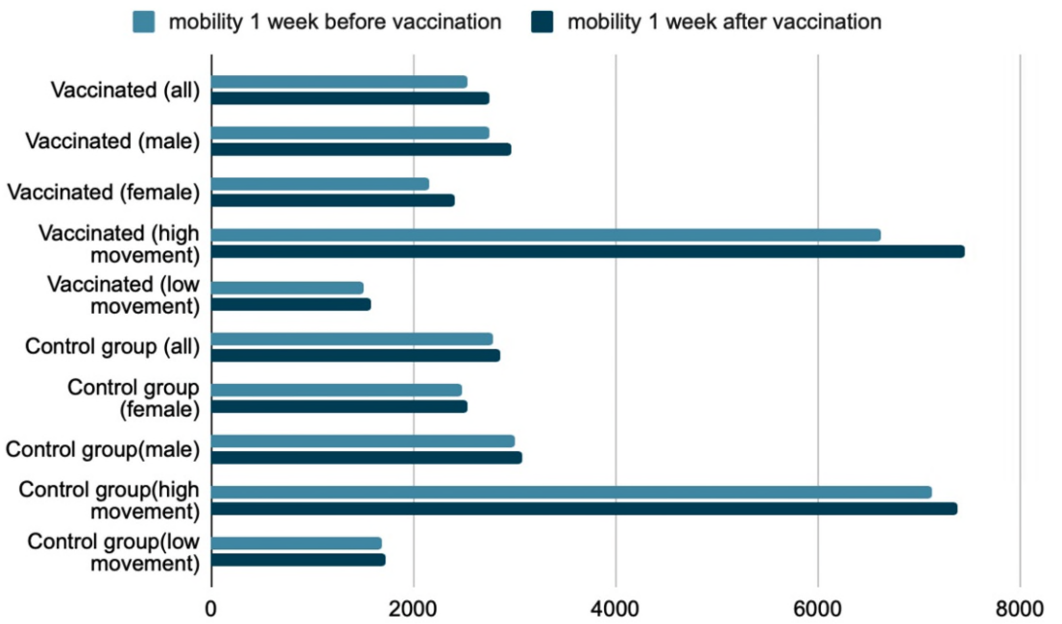
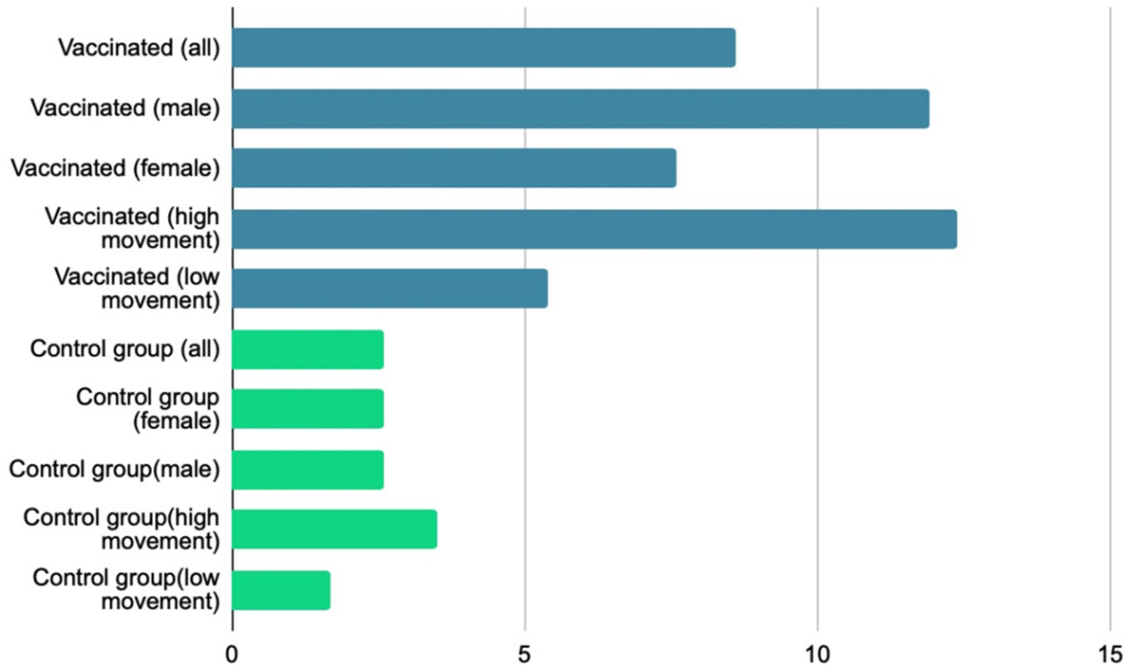


Figure 8. Percentage change in mobility in the week before and after the vaccination day, mobile phone mobility data



Relationship of behavioural adherence to NPIs to infections

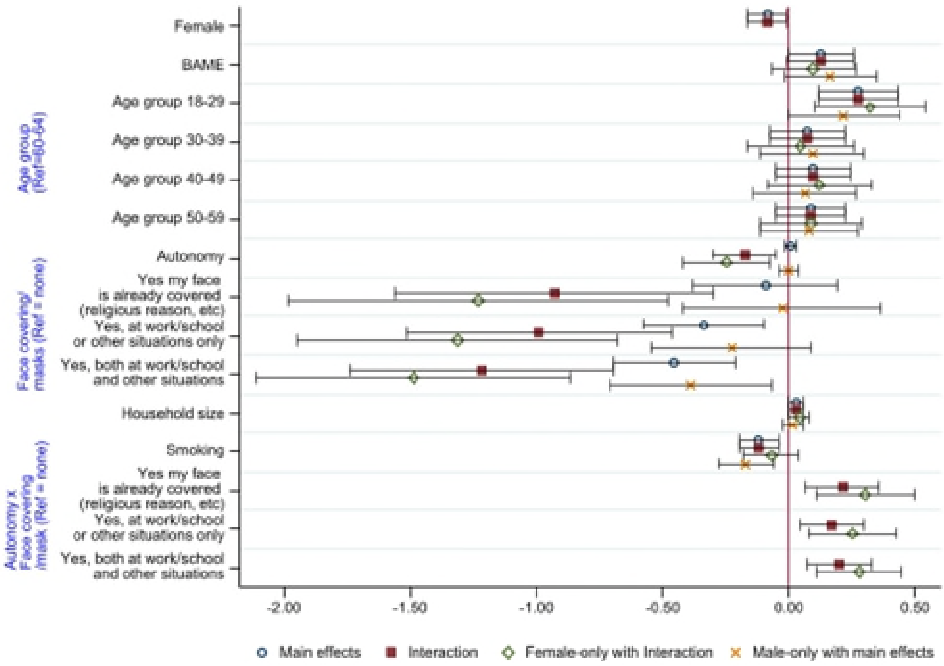
16. Barriers to vaccine uptake and ability to adhere to NPIs are related to key socio-demographic, economic, psychological and behavioural factors. As outlined in an earlier SPI-B report on self-isolation,[9] low (<20%) rates of self-isolation were concentrated in the youngest and most

economically deprived groups, related to factors such as financial support and ability to adhere, non-financial support (e.g., access to food, care), information and emotional support.

17. To extend this work, we move beyond aggregated population percentages to produce behaviourally informed empirical analyses that control for confounders and changes over time to model how socio-demographic and behavioural factors such as autonomy to comply with NPIs is related to testing positive for infection. We use the Covid Infection Study (CIS) from 10 May 2020 to 02 February 2021 of 409,009 valid tests nested in 72,866 households for individuals aged 18-64 years in multivariate multilevel logistic regression models, stratified by sex and time-period, (full results in Appendix 2).
18. Autonomy to abide by NPIs is measured via an index (i.e., days work at home, ability to maintain physical distancing at workplace, work not possible at home, travel to work requires public transport, work involves direct contact). We find that the level of autonomy does not predict infection alone, but is mitigated when individuals comply to NPIs (Figure 9). Autonomy has a large and statistically significant effect on infection only when people do not wear a face covering or mask, suggesting that engaging in protective behaviours such as face coverings can reduce the unequal effects of exposure to COVID-19, also found in previous reviews of the literature.[10] It is emphasises the need to move to more complex models beyond aggregated percentages for a more nuanced understanding and tailored communications.
19. Those in the 18-29 year old age groups have a significantly higher likelihood of infection compared to 60-64 year olds and all other age groups. Risk of infection is gendered, with a larger household size related to a significantly higher risk of infection only for women, reflecting more domestic and care duties and time in the household. For men, smoking is related to a surprisingly significantly lower likelihood of infection and always wearing a face covering or mask outdoors also predicts lower infection.[ii] The smoking is in line with 17 studies that found that current smokers had a reduced risk of testing positive for COVID-19.[11]

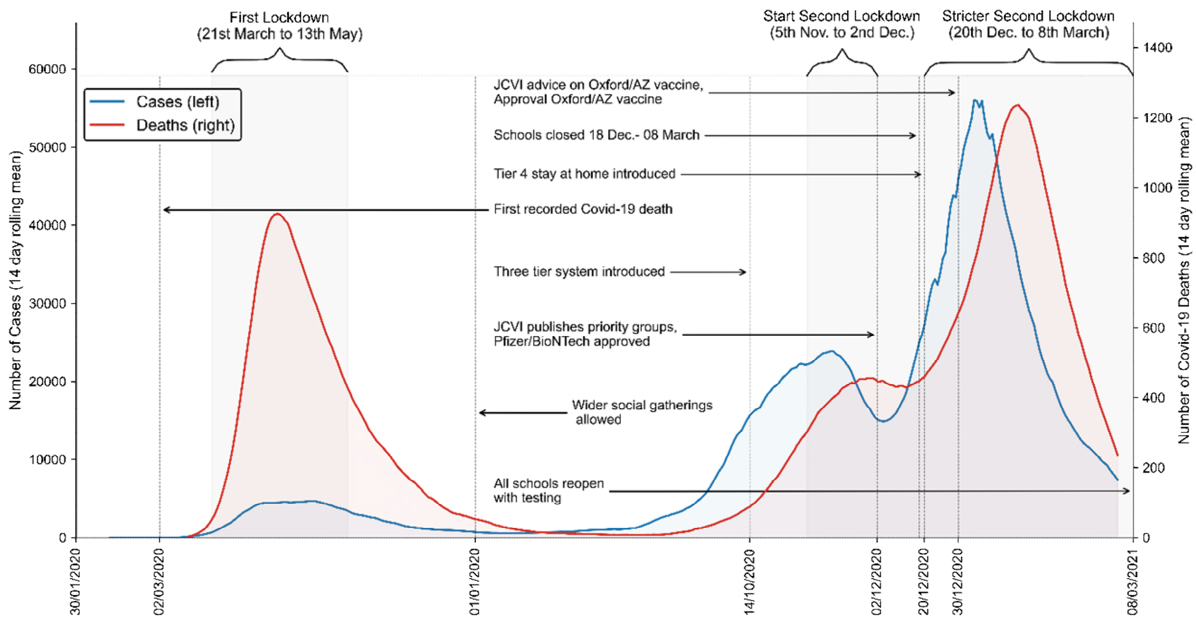
Figure 9. Logistic regression model of COVID-19 positive tests, 10 May 2020 – 02 February 2021 by key predictors and interaction effects (see Appendix for full tables)

[ii] This is a correction from the first version of this report, which inaccurately stated that smoking was associated with a higher risk of testing positive for Covid-19. All data and analysis has remained unchanged.



20. To test whether our key predictors change in relation to key policy restrictions that have been put in place to restrict infections, hospitalisation and deaths (see Figure 10), we divided the analysis into three policy periods (available in our data) of: (1) 10 May 2020 – 04 November 2020 (first lockdown to pre-second lockdown), (2) 05 November – 19 December (second lockdown and pre-Christmas period of 'lockdown light'); and, (3) 20 December – 02 February (stricter second lockdown with schools closed and introduction of Tier 4). Figure 10 illustrates the clear time-lag between infections leading to deaths, with expectations this will be disrupted by vaccinations.

Figure 10. Timeline of key restrictions in England by COVID-19 cases (left) and deaths (right), January 01 2020 to March 08 2021



Note: JCVI (Joint Committee on Vaccination and Immunisation); AZ (Astra Zeneca). Graph produced by authors using policy data for England,[12,13] and official UK Government data on COVID-19 cases and deaths,[14] smoothed into 14 day rolling means. Deaths are in red (read from right axis) and cases in blue (read from left axis) with magnitudes representing smoothed 14 day rolling means and not cumulative figures. Source: Mills, M.C. et al. (2021).

21. Our models show variation in the importance of key behavioural and socio-demographic predictors over time (see Appendix for results). Autonomy to follow NPIs in relation to infection risk is only a significant predictor between May to November 2020 (first lockdown to pre-second lockdown). The impact of wearing a face covering or mask, however, predicts a lower chance of infection consistently across the entire period. Household size is associated with higher infections between lockdown 2 'light version' (05 November – 19 December) only and smoking is only significantly related to lower infection before the second lockdown. A caveat is that the sample in the lockdown 2 'stricter version' period is much smaller, meaning that we may not have the power to detect some effects.

Public messaging

22. Our public messaging advice amplifies previous SPI-B, ethnicity sub-group and related scientific research, but here we focus on advice directly related to vaccine uptake, hesitancy and NPI compliance from our data-driven results. We reiterate the importance of positive messaging,[15] need to increase adherence among young people,[16] public health messaging for communities from different cultural backgrounds,[17,18] understanding factors influencing vaccine uptake among minority ethnic groups,[3,19] behavioural, social and economic considerations when reducing restrictions,[9,20] and impact of the COVID-19 vaccination programme on adherence to rules and guidance.[2] Previous papers often lacked the empirical COVID-19 related timely evidence to underpin this which we have updated here.
23. Our core suggestions based on the evidence presented in this report and a continuity of previous SAGE SPI-B and ethnicity sub-group advice is:
    - Develop communications from a more data-driven approach that moves beyond aggregated headline percentages and flags important disaggregated, nuanced sub-groups, confounders and intersectionality to more efficiently target low uptake and hesitancy in a more tailored manner. This will be more effective in matching daily lived experiences (e.g., needing to take public transport, large households) as opposed to large sledgehammer categories of age or broad BAME groups that may have adverse effects. This also avoids signalling out and stigmatising certain groups such as youth, particular BAME groups, or geographic areas which could have adverse reactions.
    - Given different levels of adherence to rules and guidance, strategies aimed at influencing behaviour will be more effective when co-produced and targeted, stratified by age,[16] ethnicity and cultural factors[3,18] and reflecting autonomy and ability to follow guidelines,[9] but then dividing these into more nuanced groups experiencing an intersectionality of cumulative disadvantage and daily experience (e.g., young, shielding, BAME in area of social deprivation or female, needing to take public transport, living in a large household, inability to social distance at work). Attention beyond BAME groups such as the current strong focus on Black individuals to mixed and other ethnic groups, including what in the UK is termed 'White Other' (including Eastern European individuals) is warranted given low uptake in these groups.
    - Our evidence on lack of compliance of over 80s who have been vaccinated with at least one dose within the last 3 weeks but have left home, met with persons (that is not a carer or a member of their bubble) indoors or outside, suggests communications should focus on explaining of the development of immunity and protection within the 3 weeks after the first dose.
    - Low compliance to behavioural NPIs and higher vaccine hesitancy is also related to factors beyond socio-demographic predictors including negative attitudes about lockdowns and opposition to mass testing, suggesting a different approach for these groups. This suggests increasing public understanding through multiple and alternative channels by clarifying the benefits of vaccination, the level of population immunity required and why and many of these individuals may not follow conventional media.[21]
    - Mobility data reinforces the Pareto principle that very few (around 20%) of already highly mobile individuals before vaccination increase their mobility even more after being vaccinated, suggesting that a different communication approach for this group compared to the 80% who are compliant.
    - Continuing to message about the protective effects of face coverings and masks is important particularly given that our results show that those who are more diligent (such as wearing face coverings) mitigates the unequal exposure for some groups that have little autonomy in

following COVID-19 restrictions (i.e., unable to maintain physical distancing at work, need to take public transport, work outside of home).

- As noted in a previous SPI-B report, focus on positive messages, hope and long term goals to sustain adherence to infection control behaviours.[15] Avoid blame and focus on enabling members of public to engage in adherence rather than enforcement of compliance rules. Engage in positive messaging about high levels of vaccine uptake, high levels of compliance in many groups and success of vaccine roll out and NHS and others in mobilisation.
- Offer positive alternatives when vaccination uptake is hampered due to individual barriers or constraints (e.g., longer opening times, ability to visit alternative sites, transportation, roving or place-based sites)
- Engage in clear, visual messaging of NPIs and behaviours that still need to remain in place linked to timelines related to dosage and re-dosing, keeping sufficiently clear to avoid differences between vaccines, dosing schedules

Operational components of driving uptake in Phase 2 cohort (18-49)

24. There is low vaccine uptake for those who are shielding under the age of 49, particularly in certain areas of deprivation. Considering this is a highly vulnerable group, operational efforts could be made to actively target and contact particularly the younger shielding group (and those in areas of social deprivation) more directly via particular services, channels or mobile units.
25. Given the need for large groups to take public transportation to get to work and difficulties combining work and life reconciliation, sites need to continue to be located in areas of convenience, involve employers or roving sites to reduce barriers as more groups go back to work.
26. Continue to monitor changing nuances in uptake beyond broad categories to adapt to a more fine-grained understanding of individuals' needs and everyday barriers beyond hesitancy, particularly for uptake of second doses.
27. These results help to operationalise government's 4 roadmap tests by showing how a more granular understanding of vaccine hesitancy, take-up and behavioural compliance during vaccine roll out could change assumptions, communication and operational strategies that can be used to operationalise the government's roadmap tests and aid in the delivery of vaccines, alleviating pressure on the NHS and ensuring we are not vulnerable to escape variants that undermine rollout (i.e., preventing infection and blocking transmission)

SPI-B Appendices: Behavioural considerations for vaccine uptake in Phase 2 and beyond

Date: 09 March 2021

This document is a rapid evidence analysis, based on the latest available data prepared by the University of Oxford on behalf of SPI-B (Melinda C. Mills, Xuejie Ding, David M. Brazel, Charles Rahal, Matthias Qian, William Wildi, Xiaowen Dong and Shiv Yucel, Leverhulme Centre for Demographic Science).

Appendix 1: Data and Analytical Approach

Data

Data for this rapid report relies on a literature review, but given the lack of peer-reviewed evidence to date on these questions in the context of COVID-19 also engages in the primary analysis of data.

OPENSafely COVID Vaccine coverage report.[22] Working on behalf of NHS England, OPENSafely is a secure analytics platform for electronic records. Data is a weekly report of COVID-19 vaccination coverage in England using data from 40% of general practices that TPP electronic health care record software. Detailed discussion of data and caveats are elsewhere[23] with analytical methods behind vaccine coverage in the OPENSafely GitHub repository.[24] Figures included in this report are all vaccinations up to 24 February 2021 of:

- Total population vaccinated in TPP: 6,454,259
- 80+ population vaccinated: 1,065,666 (93.6% of 1,138,669)
- 70-79 population vaccinated: 1,927,100 (92.9% of 2,073,330)
- care home population vaccinated: 76,489 (91.9% of 83,202)
- shielding (aged 16-69) population vaccinated: 538,594 (66.3% of 811,804)
- 65-69 population vaccinated: 811,097 (75.5% of 1,074,346)
- under 65s, not in other eligible groups shown population vaccinated: 2,035,306

Vaccine types and second doses: Second doses (% of all vaccinated): 216,867 (3.4%); Oxford-AZ vaccines (% of all first doses): 3,052,329 (47.3%).

Covid Infection Survey (CIS). This is the largest regular survey of coronavirus infections and antibodies.[25] The CIS has been used to examine multiple aspects and to monitor community prevalence of SARS-CoV-2.[26] Samples are collected from individuals aged 2 and older living in private households in England, randomly selected from address lists and ONS surveys. It is a repeated cross-sectional household survey with additional serial sampling and longitudinal follow-up. Data includes a questionnaire and nose and throat swabs.

ONS Opinions and Lifestyle Survey (OPN), waves 45, 46 and 47, collected the weeks of 10, 17 and 24 February respectively, which is a sample of approximately 4,000 to 4,500 people aged 16 years and older taken once per week using a cross-sectional sample of society and covers Great Britain only. Started in March 2020, it included those who took part in the Labour Force Survey and The Living Costs and Food Survey. From September 2020 onwards, the OPN sample has been taken from respondents from the Labour Market Survey, where the sampling frame is the Royal Mail's postcode address file. There is a two-stage sampling approach: household and then one individual from each household with oversampling of young and old, with a random boosted sample since October 2020. Questions in the OPN cover topics primarily related to how the coronavirus pandemic affects households and individuals in Great Britain. The average response rate is 72% (based on January 2021) with data collected by an online self-completion questionnaire or telephone interview on request (around 1% of the sample).

Over 80s Vaccines Insights Study, 15-20 February 2021 is a cross-sectional survey of 2,070 individuals aged 80 and older sampled through the Personal Demographic Service held by NHS Digital. The survey is a nationally representative sample of the over 80s population in the England based on weighted counts representative of the 2,837,000 over 80s population in England (mid-2019 population estimates), adjusted to address, age, sex and regional bias responses.

CKDelta mobile phone location data (CKD) are anonymised and aggregated GDPR-compliant call data records (CDRs) for 18,273,297 users in the period February 1st to February 28th 2021. CKDelta, a company that collected, cleaned, and anonymized the mobile phone location data from a large British mobile network operator, granted us access to the dataset under a research contract. An entry is created within the CDRs based on the on-the-fly processing of signalling messages exchanged between mobile phones and the mobile network, usually collected by mobile network operators to monitor and optimise the mobile network activities. CDRs encompass messages containing information about the identifiers of the user and of the cell phone tower handling the communication and the time stamp. The temporal resolution of the CDRs, reflected in the timestamps of the user's activity, is at a second level. The median user in our treatment group of vaccinated users has 40 daily CDR records with corresponding location observations. The spatial resolution is on a cell phone tower level. Within urban areas, the average distance from one cell phone tower to its closest neighbour is around 300 meters. In rural areas, the cell phone tower density is much lower, and cell towers are one to two kilometres apart, with the largest distance to the nearest neighbouring tower at 12 kilometres.

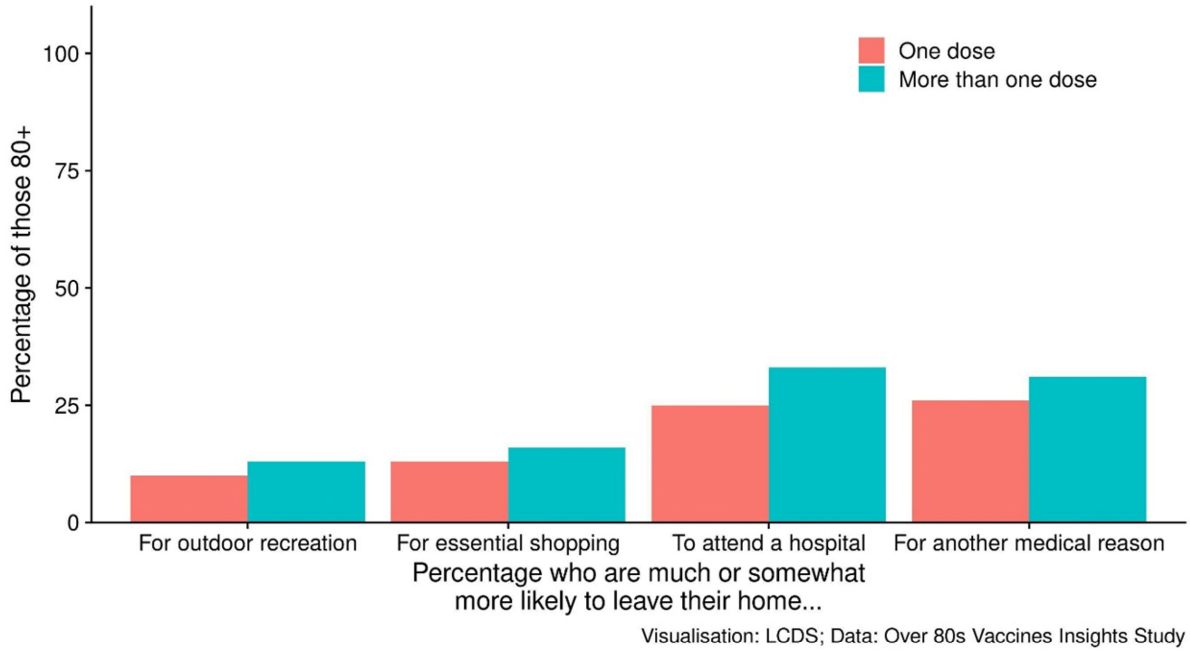
Vaccination Centres. We use data from the list of vaccination centres as of February 19 2021 (downloaded on February 23 2021).[27]

Appendix 2: Analytical methods and detailed results

2.1 Vaccination uptake and over 80s

Analysis of the OPENSafely vaccination data and over 80s vaccinated population includes descriptive aggregated figures only since individual level was not available to the analysts for this examination.

Figure 2.1 Percentage of over 80s who are much/somewhat more likely to leave home since being vaccinated by reason for leaving home and number of doses, , over 80s, 15-20 February 2021



2.2 Mobile phone mobility analyses

Data from cell towers and vaccination centres were linked to compute the distance nearest to the neighbouring tessellation zone and distance to the centroid of the compassing tessellation zone. Each vaccination site is assigned a confidence measure (e.g., low confidence characterised by major transport, infrastructure). Sensitivity checks are conducted and only individuals who have been to the vaccination centre (i.e., cell tower) only once in either Week 2 or Week 3 of February (and not before or after), which are linked to opening times of vaccination centres, are considered as vaccinated. Various robustness checks are undertaken by age (filter only 65+ for week 2 of February, 60+ for week 3 of February), distance from home to vaccination point, gyration (radius of gyration on vaccination day), time (opening hours) and home (do they go home directly after vaccination).

To determine pre- and post-vaccination changes in mobility behaviour, we match each person in the treatment group with one in a control group to compute a differences-in-differences (DID) model that mimics an RCT (randomised control trial) experimental design. Our process includes matching each vaccinated individual in the treatment group with one in the control group that has the same home tower, similar demographic profiles, and mobility measures, followed by computing mobility measures for both groups in a seven-day pre-vaccination period (depending on the vaccination day of the treatment group member) compared to a seven-day post-vaccination period. This allows us to calculate the effect of a treatment (i.e., getting vaccinated) on mobility behaviour by comparing the pre- and post-vaccination mobility behaviour for the treatment group compared to the average change for the control group.

Detailed analytical steps:

Retrieve a list of 107 vaccination centres in England as of February 19th. Associate each vaccination centre with one to three (depending on the vaccination centre's location) cell towers nearby, which may serve the area the centre is located. Remove vaccination centres for which cell towers' association is not reliable (see Figure 2 for a high confidence example and Figure 3 for a low confidence example). Towers are low confidence if they are in touristic areas or contain a hospital, as both categories increase the share of one-time visits to the site. Of the 107 vaccination centres 35 are low confidence, corresponding to 32.7%.

i. Assumption: calls made from the vaccination centre are served by at least one of the associated cell towers

ii. Impact: None

Figure 2.2 Example of a high confidence association between vaccination centre (red dot) and tessellation zone (area covered by a cell tower).

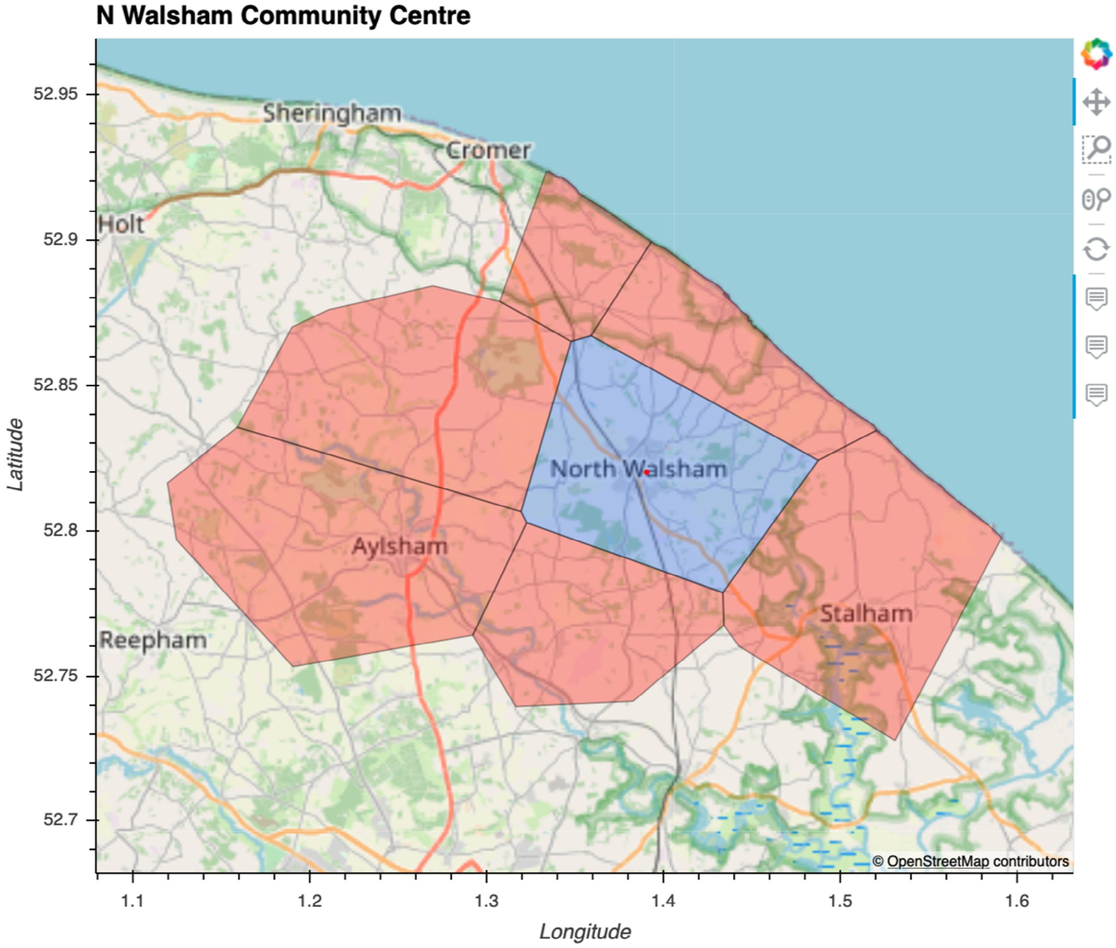
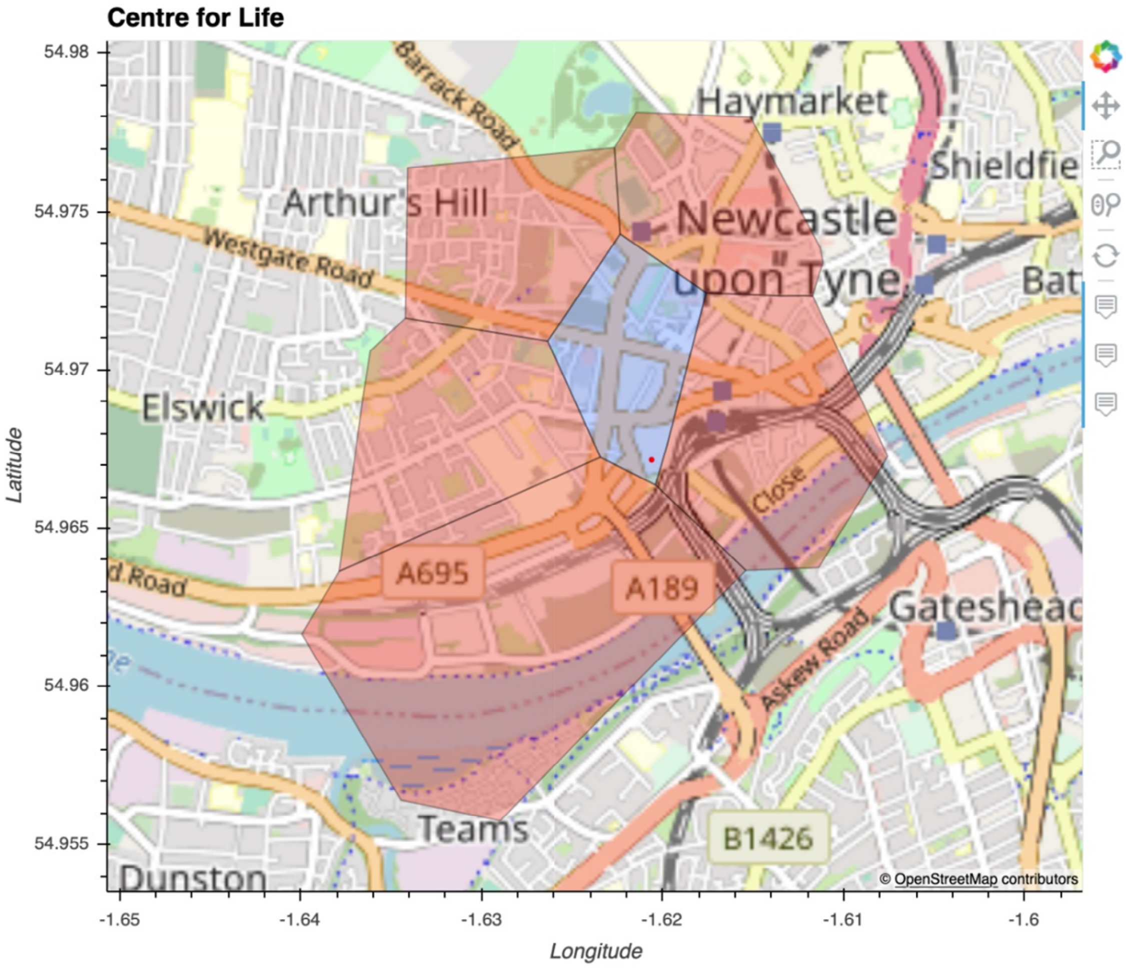


Figure 2.3 Example of a low confidence association between vaccination centre (red dot) and tessellation zone (area covered by a cell tower).



b. For each vaccination centre, identify people (treatment group) who had been connected to the cell towers associated with the vaccination centre on exactly one day in the 2nd or 3rd week of February and not on any other day in February. The treatment group is restricted to only include individuals over the age of 65 for those vaccinated in the 2nd week, and over 60 for those vaccinated in the 3rd week.
    1. Assumption: if an individual was elderly enough to be eligible for vaccination, and their cell activity indicated they were near a vaccination centre on exactly one day in February, then the individual was vaccinated at that centre
    2. Impact: both false positive (people who passed by) and false negative (people who did not use their mobile phones during vaccination) will exist, but this impact is mitigated by restricting the analysis to people who had activities on only one day during the entire month of February, and by the filtering in step c)

c. Filter members of the treatment group based on home location and movement pattern. Remove members of the treatment group for whom the detected home location has changed before and after vaccination day, and for whom the distance between home and furthest location visited on the vaccination day is more than twice that between home and vaccination centre. Users also had to have used their phones at least once every day in February to be included in the analysis. This results in a list of users who have been vaccinated in the 2nd or 3rd week of February.

Assumption: only people who have a reliable and stable home location and did not travel too far beyond the vaccination centre on the vaccination day are deemed to have received a vaccination. It is not possible to accurately measure the mobility of individuals who do not use their mobile phones with a certain regularity.

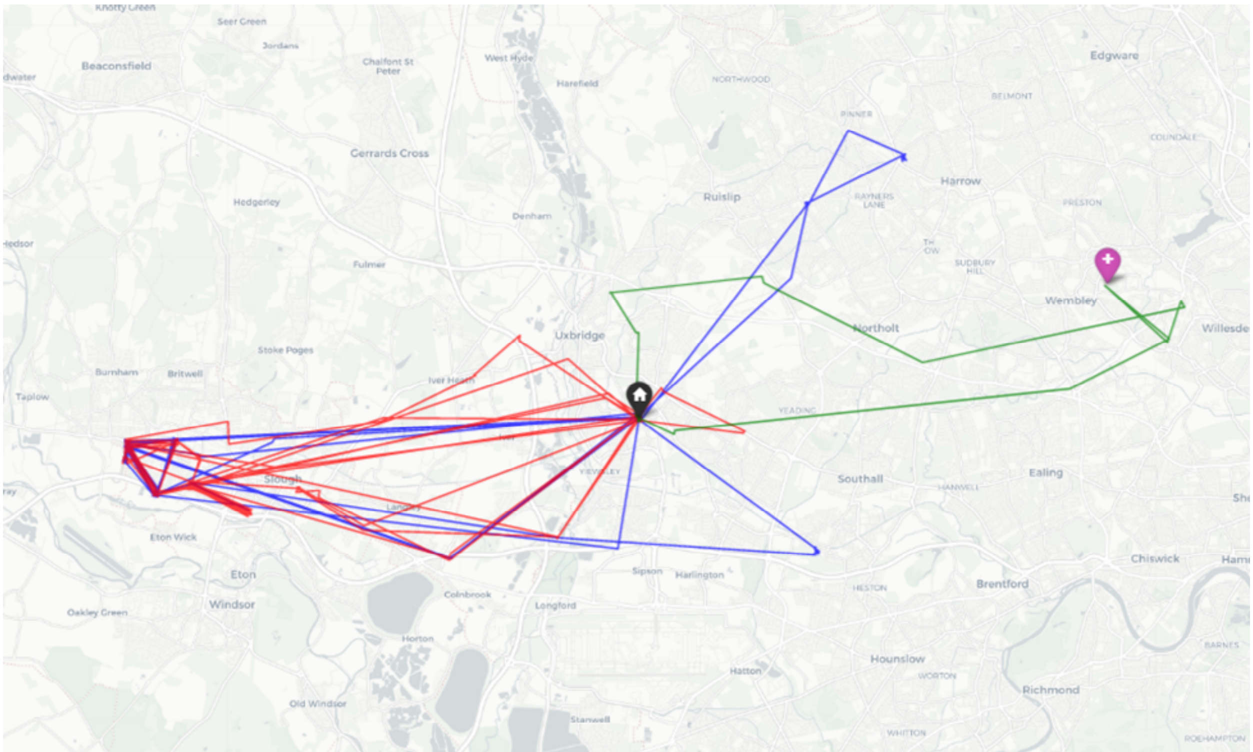
iii. Impact: reduced likelihood of false positives, at the cost of reducing the sample size.

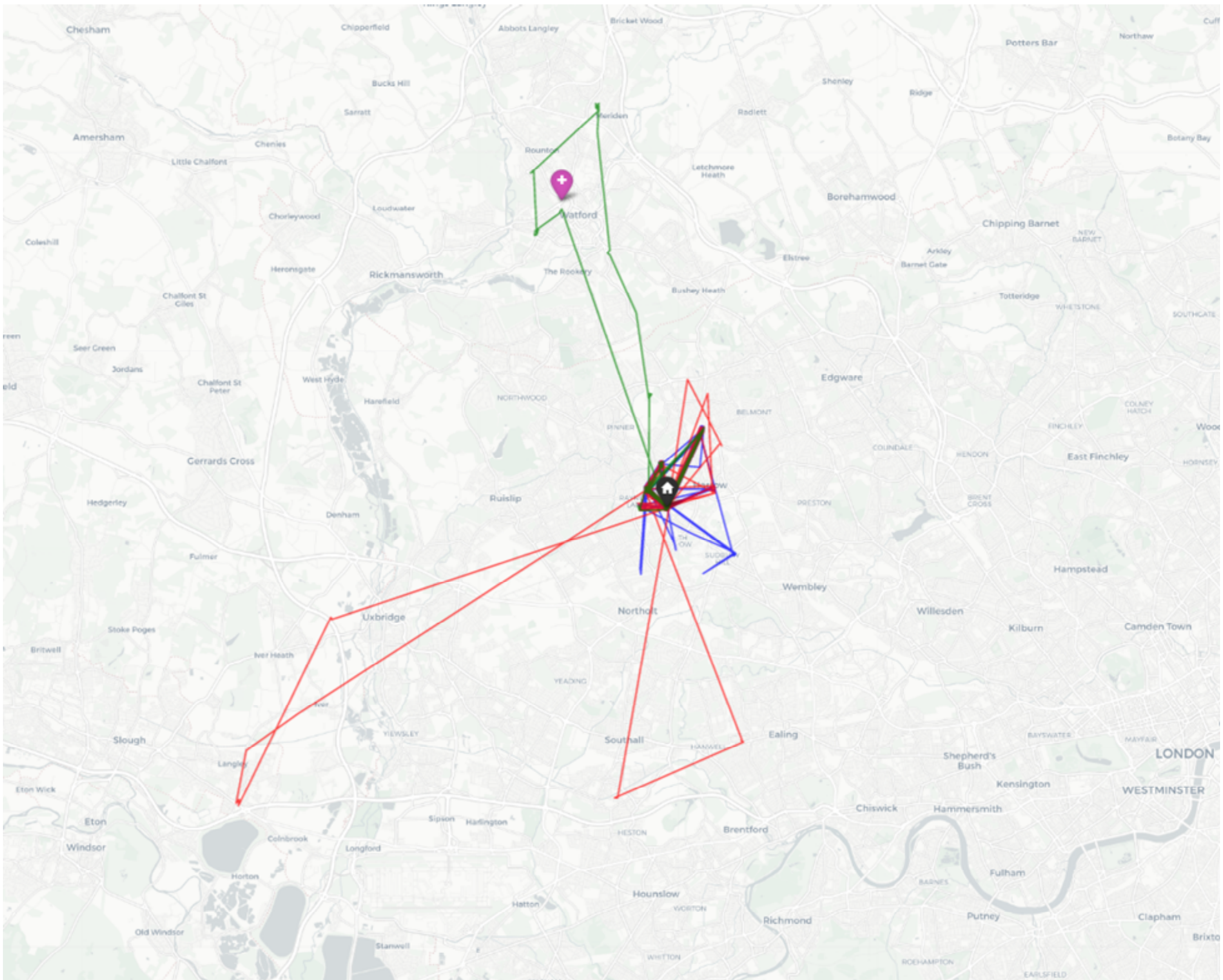
d. For people in the treatment group, compute the mobility measure (radius of gyration) on each day in a seven-day period before and after vaccination. Compute the average radius of gyration for the pre-vaccination period and post-vaccination period.

e. Repeat the computation in step d) for each member of a control group. The control group is a random sample of 4254 users aged 57-58 and therefore are not in the treatment group. Since the control group does not have a vaccination day, each control group member is matched with a treatment group member, and the same seven-day periods are used to compute the radius of gyration. Each treatment/control pair is chosen such that they have a similar level of movement (i.e., a similar average radius of gyration across the month of February).

f. Repeat the computation in steps d)-e) for female/male users and high/low movement users in the treatment and control groups. High and low movement users are defined as individuals in the top 20% and bottom 80% of the mobility distribution, respectively.

Figure 2.4 Illustrative examples of trajectories of vaccinated users one week before and after the vaccination event





Notes: The black token is the cell phone tower classified as the home location of the users. The pink token is the vaccination site. In green are the trajectories on the vaccination day. In blue are the trajectories in the week before the vaccination. In red are the trajectories in the week after the vaccination.

Mobility measures:

- Radius of gyration: the radius of gyration is a generic metric of the spatial extent of everyday mobility practices for a user. It is a function of the number of places a user visits on a day and the distance between those places. In most cases, the radius of gyration increases if the user visits more places or if the distance between the visited places is larger. The radius of gyration is unaffected by the amount of time users spend away from their residence. Mobility will be underreported if individuals do not take their phone along or when there are no CDR records generated during a trip.

  The radius of gyration is constructed though summation of the distance from all points of user i travels among the time-stamped (t) locations $l_{i,d,t}$ on day d from the trajectory's centre of mass c can be formulated as $l^c_{i,d} = 1/n \sum_{t=1} l_{i,d,t}$ on that day. Locations l are approximated by the nearest mobile phone tower. Formally, the radius of gyration $r_{i,d}$ can be expressed as:

$$r_{i,d} = \sqrt{\frac{1}{n}\sum_{t=1}\left(l_{i,d,t} - l^c_{i,d}\right)^2}.$$

Table 2.1 Change in mobility measure

	Average pre-vaccination mobility (meters)	Average post-vaccination mobility (meters)	Difference in average mobility (meters)	Difference in percentage	p-value of Wilcoxon signed-rank test	Sample size
Vaccinated (All)	2529 [2428, 2630]	2759 [2642, 2876]	218 [143, 317]	8.6%	0.000	4254
Vaccinated (Female)	2159 [2036, 2284]	2418 [2258, 2577]	257 [134, 381]	11.9%	0.001	1584
Vaccinated (Male)	2747 [2606, 2890]	2961 [2801, 3122]	213 [97, 331]	7.6%	0.000	2670
Vaccinated (High movement)	6630 [6261, 6999]	7453 [7012, 7895]	823 [418, 1229]	12.4%	0.000	851
Vaccinated (Low movement)	1503 [1466, 1540]	1585 [1547, 1624]	82 [45, 119]	5.4%	0.000	3403
Control group (All)	2783 [2675, 2890]	2855 [2744, 2966]	72 [-12, 157]	2.6%	0.005	4254
Control group (Female)	2474 [2340, 2609]	2539 [2397, 2682]	65 [-50, 183]	2.6%	0.17	1771
Control group (Male)	3003 [2846, 3160]	3080 [2920, 3241]	77 [-39, 194]	2.6%	0.012	2483
Control group (High movement)	7127 [6732, 7522]	7374 [6970, 7779]	247 [-135, 629]	3.5%	0.058	851
Control group (Low movement)	1697 [1655, 1739]	1725 [1683, 1768]	29 [-16, 73]	1.7%	0.034	3403

Notes: Pre-vaccination mobility and post-vaccination mobility refer to mobility one week before and after the vaccination day, respectively. High movement and low movement users are individuals who are among the top 20% and the bottom 80% of the mobility distribution, respectively. The control group consists of 4254 matched users from the full CKDelta dataset with age 57-58, where each member of the control group is matched to a member of the treatment group. Numbers in the square bracket represent the 95% confidence interval.

In addition to the results described in the main text, Females increase mobility by 11.9% and males by 7.6%, but the difference is insignificant when tested against the null hypothesis of equal gendered medians using the Mann-Whitney U test. For a control group of users aged 57 to 58 and matched based on their mobility in February, we find much lower mobility increases over the same period as the treatment group. Across female and male users, the mobility increased for the control group by 2.6%.

2.3 Covid Infection Study (CIS) analyses

Data and measures. We use the Covid Infection Study (CIS) from 10 May 2020 to 02 February 2021 of 409,009 valid tests nested in 72,866 households for individuals aged 18-64 years in multivariate multilevel logistic regression models, also stratified by sex and time-period

The outcome is a positive Covid-19 test, with the main predictors of sex, BAME, age group, visit date, household size, smoking, region, occupation, days since contact with any COVID-19 testing positive person, compliance to wearing a face covering/mask and autonomy to comply.

Autonomy is measured via the sum of several situations that may limit the respondents' ability to comply with the NPIs. We assigned scores to each situation as follows:

1. The CIS questionnaire asked about the number of days in a week the respondent work outside home. The autonomy score will add 1 point if the respondent reports non-zero days working outside home.
2. The questionnaire contains self-reported workplace social distancing measures. Autonomy score adds 0 if the respondents report "easy to maintain 2m", adds 1 if "relatively easy to maintain 2m", adds 2 if "difficult to maintain 2m, but can be 1m" and adds 3 if "very difficult to be more than 1m away".
3. The autonomy score adds 1 point if the respondent's main working location is "somewhere else (not your home)". The autonomy score adds 0 if the main working location is "home" or "both home and somewhere else".
4. The autonomy score adds 1 if the respondents get to and from work/school by underground/metro/light rail/tram/bus/coach/minibus; 0 if the travel method is motorbike/scooter/moped/car/van/Taxi/minicab/Bicycle/on foot/other method.
5. The autonomy score adds 1 if the respondents' work involves direct contact with patients/clients/residents/service users/customers on a day-to-day basis.

For example, a person who reports working outside home for 5 days a week (1'), whose job is difficult to maintain 2m, but can be 1m (2') and main work location is not home (1') and who cycle to work (0') and work directly with people (1') will score 5 in autonomy.

After summing up the scores we reverse coded the autonomy variable so lower score means low autonomy (more situations limiting the persons' ability to comply) and higher autonomy score indicates better ability to comply with NPIs. The range for the autonomy variable is from 0-7 and the person described in the previous example is now scored 2.

Analytical strategy. Logistic regression models are estimated with robust standard error clustered at the household level. The main model uses sex, ethnicity, age group, face covering/masks, autonomy and other control variables to predict COVID-19 positive infection. Model 2 adds an interaction term between autonomy and face covering/masks. Model 3 is the same as model 2 but only includes females. Model 4 is the same as the main model but only includes males. This was decision was made since when we tried to add the interaction term for men only model, the interaction terms were not significant, the model fit did not increase, and the main effect also disappears. We therefore consider the interaction terms in the male model as an unnecessary control and only reported the main models for men. Next we stratified the models by periods, including 1) 10 May - November 04 (pre-lockdown 2), 2) 05 November to December 19 (lockdown 2 'light version'), and 3) 20 December to Feb 02 (Lockdown 2 stricter). For the first two periods, we were able to fit the model with the interaction term, and for the third period we had to fit the main model without the interaction term for the same reason mentioned above.

Table 2.2. Logistic regression models of Covid-19 testing positive, CIS

Outcome: infection	Main effect		Interaction		Interaction + female only		Main effect + male only	
Female	-0.09*	(0.04)	-0.09*	(0.04)				
BAME	0.13	(0.07)	0.13	(0.07)	0.10	(0.09)	0.16	(0.09)
Age group (Ref = 60-64)	ref.		ref.		ref.		ref.	
18-29	0.27***	(0.08)	0.28***	(0.08)	0.32**	(0.11)	0.22	(0.11)
30-39	0.07	(0.08)	0.07	(0.08)	0.05	(0.11)	0.09	(0.10)
40-49	0.09	(0.07)	0.10	(0.07)	0.12	(0.10)	0.06	(0.10)
50-59	0.08	(0.07)	0.09	(0.07)	0.09	(0.10)	0.08	(0.10)
Visit date	0.01***	(0.00)	0.01***	(0.00)	0.01***	(0.00)	0.01***	(0.00)
Autonomy	0.01	(0.01)	-0.17**	(0.06)	-0.25**	(0.09)	-0.00	(0.02)
Face covering or masks (Ref = not wearing face covering or mask)								
Yes my face is already covered	-0.09	(0.15)	-0.93**	(0.32)	-1.23**	(0.38)	-0.03	(0.20)
Yes at work/school/other situations only	-0.34**	(0.12)	-0.99***	(0.27)	-1.31***	(0.32)	-0.23	(0.16)
Yes usually both work/school/other	-0.45***	(0.12)	-1.22***	(0.27)	-1.49***	(0.32)	-0.39*	(0.16)
Contact with COVID-19 positive people (Ref = no contact)								
0-14 days	2.38***	(0.04)	2.38***	(0.04)	2.33***	(0.06)	2.43***	(0.06)
15-28 days	1.43***	(0.06)	1.43***	(0.06)	1.38***	(0.08)	1.49***	(0.08)
29-60 days	0.58***	(0.07)	0.58***	(0.07)	0.51***	(0.10)	0.65***	(0.11)
61-90 days	0.14	(0.12)	0.14	(0.12)	0.23	(0.16)	0.00	(0.18)
91+ days	0.22	(0.13)	0.22	(0.13)	0.17	(0.18)	0.26	(0.18)
Household size	0.03	(0.02)	0.03	(0.02)	0.04*	(0.02)	0.02	(0.02)
Smoke	-0.12**	(0.04)	-0.12**	(0.04)	-0.07	(0.06)	-0.17**	(0.06)
Region (Ref = Northeast)								
Northwest	0.16	(0.10)	0.16	(0.10)	0.13	(0.12)	0.20	(0.13)
Yorks Humber	-0.06	(0.10)	-0.06	(0.10)	-0.03	(0.13)	-0.09	(0.14)
East midlands	-0.21	(0.11)	-0.21	(0.11)	-0.30*	(0.14)	-0.11	(0.14)

West midlands	-0.26*	(0.11)	-0.26*	(0.11)	-0.21	(0.13)	-0.33*	(0.14)
East	-0.61***	(0.10)	-0.61***	(0.10)	-0.62***	(0.13)	-0.60***	(0.14)
London	-0.15	(0.10)	-0.15	(0.10)	-0.19	(0.12)	-0.10	(0.13)
South East	-0.36***	(0.10)	-0.36***	(0.10)	-0.33**	(0.12)	-0.39**	(0.13)
South West	-0.80***	(0.12)	-0.80***	(0.12)	-0.81***	(0.14)	-0.80***	(0.16)
Occupation (Ref = Health professionals)								
Corporate managers and directors	0.53***	(0.11)	0.52***	(0.11)	0.52***	(0.14)	0.63***	(0.18)
Other managers and proprietors	0.74***	(0.12)	0.73***	(0.12)	0.66***	(0.18)	0.87***	(0.20)
Science research engineering and technology professionals	0.41***	(0.12)	0.40**	(0.12)	0.11	(0.21)	0.60**	(0.19)
Health professionals	0.00	(.)	0.00	(.)	0.00	(.)	0.00	(.)
Teaching and educational professionals	0.42***	(0.09)	0.40***	(0.09)	0.34***	(0.10)	0.59**	(0.18)
Business media and public service professionals	0.39***	(0.11)	0.38***	(0.11)	0.44**	(0.15)	0.43*	(0.19)
Science engineering and technology associate professionals	0.37*	(0.17)	0.35*	(0.17)	0.24	(0.26)	0.53*	(0.25)
Health and social care associated professionals	0.38*	(0.15)	0.38*	(0.15)	0.23	(0.17)	0.65*	(0.29)
Protective service occupations	0.49***	(0.13)	0.47***	(0.13)	0.75***	(0.19)	0.44*	(0.20)
Culture media and sports occupations	0.37*	(0.14)	0.35*	(0.14)	0.48**	(0.18)	0.30	(0.25)
Business and public service associated professionals	0.54***	(0.11)	0.53***	(0.11)	0.50***	(0.14)	0.65***	(0.19)
Administrative occupations	0.63***	(0.10)	0.61***	(0.10)	0.59***	(0.11)	0.70***	(0.20)
Secretarial and related occupations	0.78***	(0.13)	0.77***	(0.13)	0.76***	(0.14)	0.07	(0.53)
Skilled agricultural and related trades	-0.07	(0.29)	-0.08	(0.29)	0.06	(0.52)	0.01	(0.38)
Skilled metal electrical and electronic trades	0.70***	(0.12)	0.68***	(0.12)	0.86	(0.48)	0.82***	(0.19)
Skilled construction and building trades	0.78***	(0.13)	0.76***	(0.13)	-0.71	(1.02)	0.93***	(0.19)
Textiles printing and other skilled trades	0.37	(0.20)	0.36	(0.20)	0.49	(0.28)	0.35	(0.29)
Caring personal service occupations	0.63***	(0.09)	0.62***	(0.09)	0.58***	(0.10)	0.75***	(0.21)

Leisure travel and related personal service occupations	0.73***	(0.21)	0.72***	(0.21)	0.43	(0.26)	1.25***	(0.32)
Sales occupation	0.71***	(0.11)	0.69***	(0.11)	0.57***	(0.14)	0.94***	(0.21)
Customer service occupations	0.54**	(0.17)	0.53**	(0.17)	0.39	(0.20)	0.83**	(0.31)
Process plant and machine operatives	0.67***	(0.16)	0.65***	(0.16)	1.11**	(0.38)	0.70**	(0.22)
Transport and mobile machine driver and operatives	0.79***	(0.13)	0.77***	(0.13)	0.47	(0.35)	0.93***	(0.19)
Elementary trades and related occupations	0.88***	(0.24)	0.86***	(0.24)	0.85	(0.53)	1.01***	(0.29)
Elementary administration and service occupations	0.70***	(0.11)	0.69***	(0.11)	0.60***	(0.14)	0.86***	(0.18)
Number of tests	-0.07***	(0.01)	-0.07***	(0.01)	-0.08***	(0.01)	-0.06***	(0.01)
Autonomy x Face covering/masks (Ref = No face covering/mask)								
Autonomy x Yes my face is already covered			0.21**	(0.07)	0.30**	(0.10)		
Autonomy x Yes at work/school/other situations only			0.17**	(0.06)	0.25**	(0.09)		
Autonomy x Yes usually both work/school/other			0.20**	(0.06)	0.28**	(0.09)		
_cons	- 287.35***	(11.57)	- 286.98***	(11.58)	- 291.39***	(14.83)	- 283.56***	(15.81)
N	409009		409009		217920		191089	
pseudo R-sq	0.133		0.133		0.133		0.136	

Note: Robust standard errors in parentheses, standard errors are clustered at the household level, * p<0.05, **p<0.01, ***p<0.001

Table 2.3. Logistic regression models of Covid-19 testing positive by period, CIS

Outcome: infection	01 May 2020-04 Nov 2020		05 Nov 2020 – 19 Dec 2020		20 Dec 20202 – 02 Feb 2020	
Female	-0.14*	(0.07)	-0.03	(0.05)	-0.17***	(0.05)
BAME	0.12	(0.13)	0.24*	(0.11)	-0.09	(0.09)
Age group (Ref = 60-64)						
18-29	0.28	(0.15)	0.05	(0.12)	0.40***	(0.12)
30-39	-0.03	(0.15)	-0.10	(0.12)	0.18	(0.11)
40-49	-0.14	(0.15)	-0.04	(0.12)	0.25*	(0.11)
50-59	0.13	(0.14)	-0.08	(0.11)	0.19	(0.11)
Visit date	0.03***	(0.00)	-0.00	(0.00)	0.00*	(0.00)
Autonomy	-0.44**	(0.16)	-0.13	(0.08)	-0.00	(0.02)
Face covering or masks (Ref = not wearing face covering or mask)						
Yes my face is already covered	-1.54*	(0.65)	-1.20**	(0.44)	0.11	(0.27)
Yes at work/school/other situations only	-1.28*	(0.55)	-1.19**	(0.37)	-0.43*	(0.20)
Yes usually both work/school/other	-1.60**	(0.55)	-1.61***	(0.37)	-0.55**	(0.20)
Autonomy x Face covering/masks (Ref = No face covering/mask)						
Autonomy x Yes my face is already covered	0.53**	(0.17)	0.16	(0.10)		
Autonomy x Yes at work/school/other situations only	0.44**	(0.16)	0.12	(0.09)		
Autonomy x Yes usually both work/school/other	0.50**	(0.16)	0.19*	(0.09)		
Contact with COVID-19 positive people (Ref = no contact)						
0-14 days	2.16***	(0.08)	2.27***	(0.07)	2.34***	(0.07)
15-28 days	1.10***	(0.14)	1.41***	(0.10)	1.41***	(0.09)
29-60 days	0.53*	(0.22)	0.75***	(0.11)	0.46***	(0.11)
61-90 days	0.64	(0.58)	0.23	(0.24)	0.15	(0.14)
91+ days	0.37	(0.34)	0.46	(0.25)	0.15	(0.15)

Household size	0.03	(0.03)	0.05*	(0.03)	0.02	(0.02)
Smoke	-0.16*	(0.08)	-0.03	(0.06)	-0.05	(0.06)
Region (Ref = Northeast)						
Northwest	0.22	(0.17)	0.19	(0.16)	0.09	(0.13)
Yorks Humber	-0.01	(0.18)	0.17	(0.17)	-0.52**	(0.16)
East midlands	-0.32	(0.20)	0.03	(0.17)	-0.31	(0.16)
West midlands	-0.61**	(0.20)	-0.10	(0.18)	-0.09	(0.15)
East	-1.27***	(0.21)	-0.65***	(0.17)	-0.18	(0.14)
London	-0.68***	(0.19)	-0.26	(0.16)	0.26*	(0.13)
South East	-0.94***	(0.20)	-0.35*	(0.17)	0.02	(0.13)
South West	-1.15***	(0.23)	-0.66***	(0.20)	-0.63***	(0.17)
Number of tests	-0.21***	(0.02)	-0.09***	(0.02)	0.00	(0.01)
_cons	-594.03***	(55.12)	10.87	(49.96)	-110.43*	(51.92)
N	187453		142056		84067	
pseudo R-sq	0.147		0.099		0.116	

Note: Robust standard errors in parentheses, standard errors are clustered at the household level, * p<0.05, **p<0.01, ***p<0.001

Figure 2.2. Visualization of Table 2.2 using selected key variables.

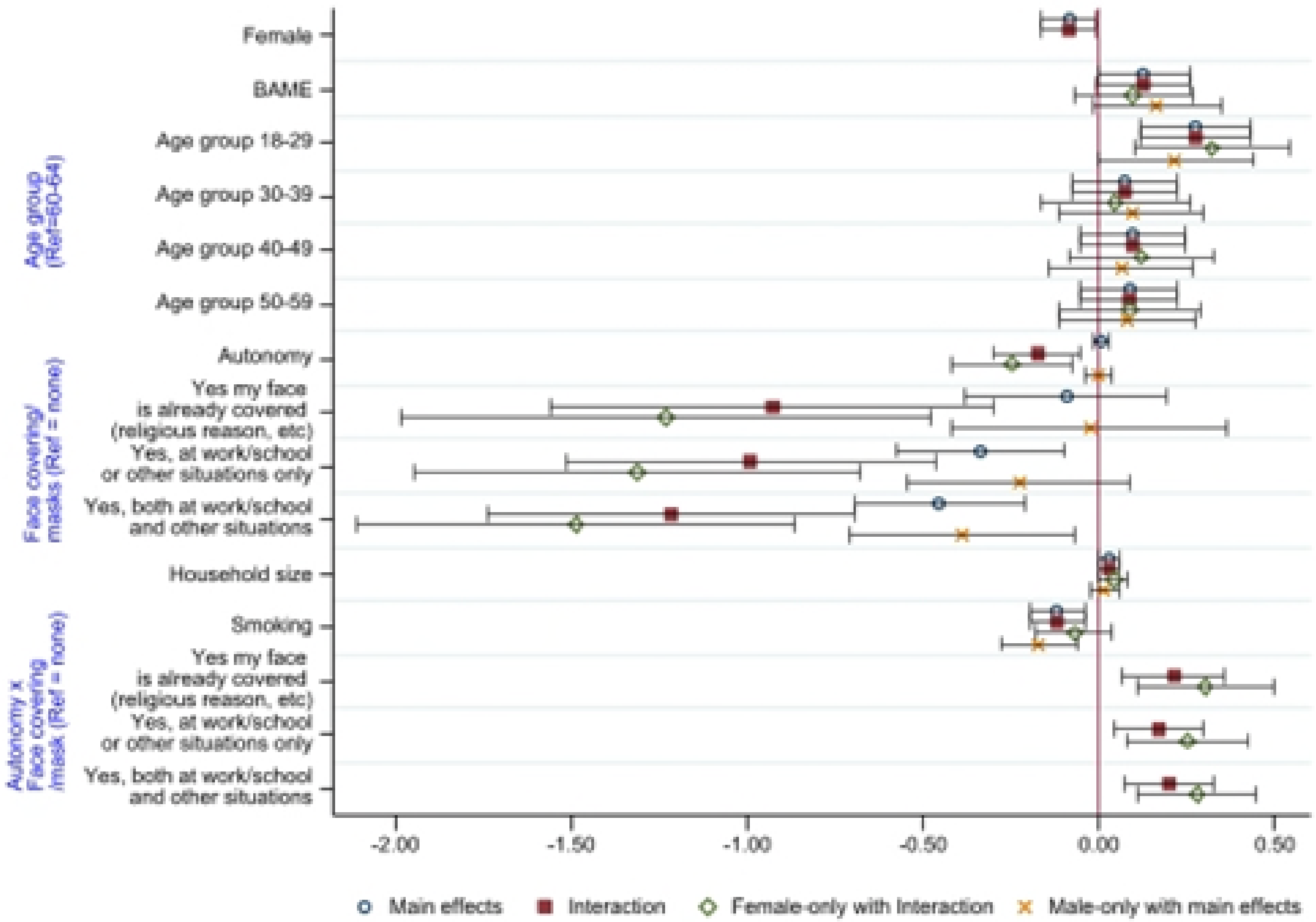
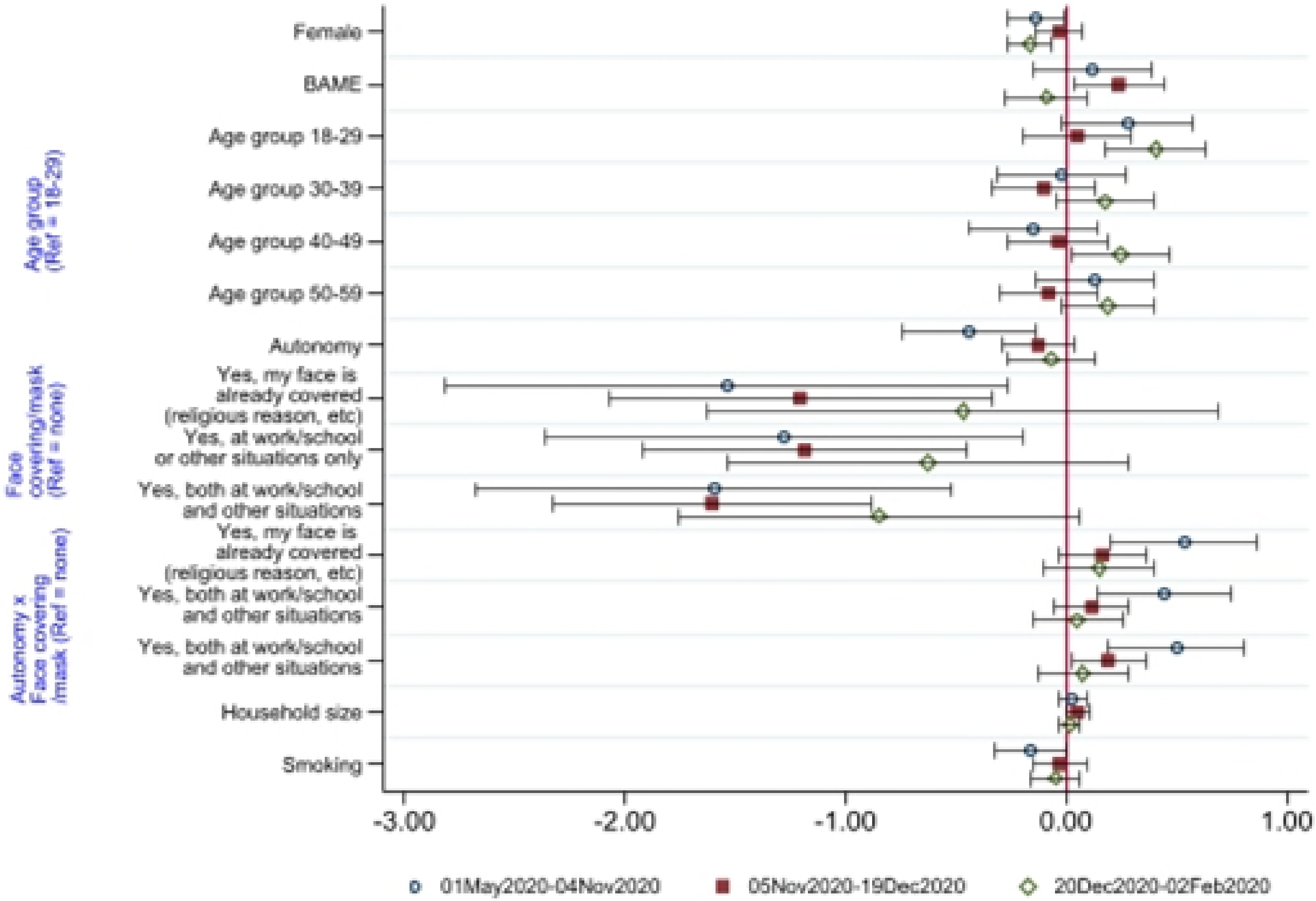


Figure 2.3 Visualization of Table 2.3 using selected key variables.



2.4 Opinions and Lifestyle survey analyses

Vaccine hesitancy

We derived vaccine hesitancy as a binary variable defined from three questions of individuals who:

- have been vaccinated are not hesitant (coded FALSE).
- have been offered a vaccine and scheduled an appointment are not hesitant. Individuals who refused an offer are hesitant (coded TRUE).
- said that they were very or fairly likely to accept an offer are not hesitant. Individuals who said that they were neither likely nor unlikely, fairly unlikely, very unlikely, or didn't know if they would accept an offer are hesitant.

We classified 11,885 observations as not hesitant and 639 as hesitant, with 54 missing. We then performed a Bayesian logistic regression (see Table 2.4), assessing the association between vaccine hesitancy and the key covariates of age, sex, geographical region, ethnicity, education, whether employed, support for mass testing, support for lockdown and also broken down by several key NPI behavioural regulations:

- Size of largest indoor meeting in past week, excluding education or work
- Probability of not wearing a face covering in the next week
- Avoided direct physical contact in past week
- Frequency of hand washing in past week
- Wore face covering in past week

Adherence to NPIs, stratified by groups

We estimated a Poisson model (see Table 2.5) with the outcome of interest in our models as NPIs, ranging from 0-4. NPIs are measured as counts of the following events: indoor gathering >6; outdoor gathering >6; in the past seven days, when met up with people outside household, can't often maintain social distancing; when had visitor at home, didn't take actions to reduce the spread of the COVID19; didn't avoid physical contact with others when outside; Not often wash hands after returning home; not use face covering when outside). Higher score in NPIs means more NPIs violation.

Autonomy (ranging from 0-3) is the sum of: (1) not able to work from home; (2) in the past seven days; left home for travelling to and from work; and (3) travel via public transport.

Daily struggle (ranging from 0-4) is measure by counts of events including (1) difficult to pay usual household bills; (2) can't afford to pay an unexpected but necessary expense of £850; (3) had to borrow more money or use more credit than usual; and (4) have less money to spend on food.

Table 2.4 Parameter estimates from a Bayesian logistic regression of vaccine hesitancy, 10-24 February 2021, Great Britain

Term	**Estimate**	**SE**	**Lower 95% credible interval**	**Upper 95% credible interval**
Intercept	4.13	0.54	3.08	5.17
Age	-0.05	0.00	-0.05	-0.04
Region, relative to East Midlands				
East of England	0.09	0.23	-0.37	0.53
London	0.03	0.24	-0.42	0.50
North East	-0.15	0.31	-0.73	0.45
North West	0.12	0.22	-0.29	0.57
Scotland	-0.71	0.43	-1.58	0.06
South East	-0.14	0.22	-0.56	0.29
South West	-0.14	0.23	-0.59	0.32
Wales	0.54	0.40	-0.29	1.28
West Midlands	0.21	0.23	-0.23	0.68
Yorkshire and The Humber	-0.28	0.24	-0.75	0.18
Male	-0.35	0.11	-0.57	-0.15
Ethnicity, relative to White				
Asian	0.12	0.30	-0.50	0.66
Black	1.51	0.34	0.80	2.16
Mixed	0.71	0.29	0.05	1.26
Chinese or other	0.78	0.39	0.02	1.48
Has a degree	-0.21	0.11	-0.44	0.00
Is employed	0.04	0.12	-0.19	0.27
Size of largest indoor meeting in past week, excluding education or work	-0.03	0.03	-0.09	0.04
Probability of not wearing a face covering in the next week	0.16	0.07	0.03	0.30
Avoided direct physical contact in past week	-0.45	0.17	-0.78	-0.12
Frequency of hand washing in past week	0.12	0.06	0.00	0.23
Wore face covering in past week	-0.37	0.29	-0.93	0.17
Support for mass testing	-0.80	0.05	-0.92	-0.69
Support for lockdown	-0.42	0.05	-0.51	-0.32
N	10,879			

Table 2.5 Poisson regression on adherence to NPIs, 10-24 February 2021, Great Britain

Outcome: Adherence to NPIs (higher score means low compliance)	Coef.	SE
Female	-0.232***	(0.040)
Age group (Ref = 70+)		
16-29	0.457***	(0.091)
30-39	0.109	(0.095)
40-49	-0.040	(0.098)
50-59	0.014	(0.089)
60-69	-0.193*	(0.078)
Vaccine	-0.027	(0.059)
BAME	-0.400***	(0.094)
Degree	0.037	(0.041)
Employed	0.141**	(0.049)
Household size	0.043*	(0.019)
Autonomy	-0.017	(0.029)
Daily struggle	-0.142***	(0.034)
Oppose mass testing	0.057*	(0.023)
Oppose the second lockdown	0.329***	(0.019)
Interview wave (Ref = Feb 10)		
Wave Feb 17	0.130**	(0.049)
Wave Feb 24	0.213***	(0.049)
Region (Ref = North East)		
North West	-0.030	(0.108)
Yorkshire and the Humber	0.000	(0.110)
East midlands	-0.027	(0.113)
West midlands	0.021	(0.111)
East of England	-0.035	(0.109)
London	-0.035	(0.113)
South East	0.008	(0.103)
South West	0.095	(0.106)
Wales	0.082	(0.183)
Scotland	0.100	(0.142)
_cons	-2.241***	(0.164)
N	12109	
pseudo R-sq	0.058	

Standard errors in parentheses, *p<0.05, **p<0.01, ***p<0.000

Table 2.6 Linear regression and logistic regression on adherence to individual NPIs, 10-24 February 2021, Great Britain

	Social distancing	**Max number of people met indoor**	**Avoid physical contact**	**Wash hands**	**Face covering: Past 7 days**	**Face covering: Next 7 days**
Female	0.024	0.079*	-0.207*	-0.143***	-0.376**	-0.080***
	(0.035)	(0.038)	(0.086)	(0.015)	(0.115)	(0.013)
Age group (Ref = 70+)						
16-29	0.462***	-0.087	0.825***	0.301***	-0.959***	-0.089**
	(0.081)	(0.089)	(0.202)	(0.035)	(0.272)	(0.030)
30-39	0.155	-0.000	0.370	0.146***	-1.381***	-0.152***
	(0.083)	(0.090)	(0.212)	(0.035)	(0.296)	(0.030)
40-49	0.044	-0.044	0.507*	0.023	-1.295***	-0.157***
	(0.082)	(0.089)	(0.208)	(0.035)	(0.293)	(0.030)
50-59	0.080	0.001	0.405*	0.023	-0.972***	-0.123***
	(0.073)	(0.080)	(0.194)	(0.031)	(0.255)	(0.027)
60-69	0.003	0.061	-0.026	-0.051*	-0.370*	-0.050*
	(0.058)	(0.065)	(0.176)	(0.025)	(0.184)	(0.022)
Vaccine	-0.005	-0.090	-0.026	-0.001	-0.361*	-0.019
	(0.049)	(0.053)	(0.123)	(0.021)	(0.177)	(0.018)
BAME	-0.003	-0.416***	0.212	-0.185***	-0.022	-0.021
	(0.087)	(0.083)	(0.168)	(0.033)	(0.270)	(0.028)
Degree	0.076*	0.153***	-0.301***	0.026	-0.060	-0.020
	(0.036)	(0.039)	(0.090)	(0.015)	(0.117)	(0.013)
Employed	0.054	0.015	0.211*	0.035	0.118	-0.001
	(0.043)	(0.047)	(0.107)	(0.018)	(0.140)	(0.016)
Household size	-0.011	0.264***	-0.062	-0.019*	0.074	0.004
	(0.018)	(0.020)	(0.041)	(0.008)	(0.061)	(0.007)
Autonomy	0.021	0.012	-0.030	-0.017	0.293**	0.016

	(0.029)	(0.030)	(0.060)	(0.011)	(0.104)	(0.010)
Daily struggle	-0.062*	-0.039	-0.001	-0.059***	-0.281*	-0.008
	(0.031)	(0.033)	(0.070)	(0.013)	(0.113)	(0.011)
Oppose mass testing	0.004	-0.017	-0.016	0.037***	0.260***	0.062***
	(0.023)	(0.025)	(0.052)	(0.010)	(0.066)	(0.009)
Oppose the second lockdown	0.180***	0.093***	0.334***	0.144***	0.346***	0.130***
	(0.021)	(0.024)	(0.043)	(0.009)	(0.058)	(0.008)
Survey Wave (Ref = Feb 10)						
Wave Feb 17	0.063	0.141**	0.043	0.006	0.071	0.007
	(0.042)	(0.046)	(0.107)	(0.018)	(0.146)	(0.016)
Wave Feb 24	0.123**	0.078	0.137	0.018	0.363**	0.006
	(0.043)	(0.047)	(0.105)	(0.018)	(0.139)	(0.016)
North west	-0.103	-0.123	0.050	-0.012	0.250	0.021
	(0.101)	(0.104)	(0.238)	(0.041)	(0.341)	(0.035)
Yorkshire and the Humber	-0.147	-0.068	-0.032	0.021	0.258	0.038
	(0.102)	(0.106)	(0.246)	(0.042)	(0.348)	(0.036)
East midlands	-0.153	-0.227*	0.052	0.030	0.005	-0.009
	(0.103)	(0.108)	(0.247)	(0.042)	(0.365)	(0.036)
West midlands	-0.165	-0.037	-0.145	0.016	0.375	0.031
	(0.103)	(0.107)	(0.252)	(0.042)	(0.346)	(0.036)
East of England	-0.144	-0.187	-0.003	-0.002	0.292	0.048
	(0.100)	(0.104)	(0.242)	(0.041)	(0.341)	(0.035)
London	-0.194	-0.312**	0.124	-0.076	0.434	0.061
	(0.105)	(0.109)	(0.245)	(0.043)	(0.351)	(0.037)
South east	-0.085	-0.198*	0.010	-0.018	0.496	0.032
	(0.097)	(0.099)	(0.230)	(0.039)	(0.323)	(0.034)
South west	-0.205*	-0.175	0.219	0.027	0.462	0.069*
	(0.098)	(0.103)	(0.234)	(0.040)	(0.332)	(0.035)

Wales	-0.318	-0.011	0.023	0.045	0.324	0.072
	(0.174)	(0.189)	(0.424)	(0.074)	(0.550)	(0.063)
Scotland	-0.058	-0.287*	0.429	-0.055	0.085	-0.041
	(0.125)	(0.143)	(0.294)	(0.056)	(0.468)	(0.048)
_cons	0.929***	1.575***	-3.540***	1.294***	-4.634***	0.980***
	(0.153)	(0.161)	(0.357)	(0.062)	(0.523)	(0.054)
N	2915	12089	11122	11187	11023	11890
adj. R-sq	0.073	0.025		0.073		0.046
pseudo R-sq			0.042		0.057	

Note: Standard errors in parentheses, *p<0.05, **p<0.01, ***p<0.001. Logistic regressions are applied for models predicting physical contact and face coverings. Others are linear regression models. Social distancing is measured by “In the past seven days, when you have met up with people outside your household, or support bubble, or childcare bubble, how often have you maintained social distancing?” 0 = I have not met up with anyone outside my household or support bubble; 1 = Always, 2 = Often, 3 = Sometimes, 4 = Not very often, 5 = Never. Max number of people met indoor is measure by “Excluding work or education, please think of the largest group that you have met with indoors in the past seven days. How many people were in the group including yourself?” Avoid physical contact is measured by “In the past seven days, have you avoided physical contact with others when outside your home?” 1 = No, and 0 = Yes. Hand wash is measured by “In the past seven days, how often did you wash your hands with soap and water straight away after returning home from a public place?” 1 = Always, 2 = Often, 3 = Sometimes, 4 = Not very often, 5 = Never. Face covering: past 7 days is measured by “In the past seven days, have you used a face covering when outside your home to slow the spread of the coronavirus (COVID-19)?” 1 = No, and 0 = Yes.

Face covering: next 7 days is measured by “In the next seven days, how likely or unlikely are you to wear a face covering when outside your home to slow the spread of coronavirus (COVID-19)?” 1 = Very likely, 2 = Fairly likely, 3 = Neither likely nor unlikely, 4 = Fairly unlikely, 5 = Very unlikely

Appendix 3. GRADE Recommendations: Quality of Evidence and Strength of Recommendations

To provide explicit, comprehensive and transparent advice, we rate the quality of our evidence and strength of recommendations according to the standard GRADE (Grading of Recommendations Assessment, Development and Evaluation) system.[28] This approach weighs the quality of evidence against recommendations. High quality evidence that an intervention's desirable effects are clearly greater than its undesirable effects, warrants for instance, a strong recommendation. Uncertainty about the trade-offs – due to either low quality evidence or unknown effects – is granted a weak recommendation.

As with all surveys, estimates are associated with a margin of error.

Significance testing and confidence intervals are used to test for differences. Where a difference is statistically significantly different, there is greater confidence that the difference really exists.

If similar significant differences are replicated across multiple data sources, a higher quality confidence is given.

Data / Topic	Type of research	Strengths	Limitations	Level quality of evidence
OPENSafely COVID Vaccine coverage report	COVID-19 vaccine coverage in England	• Linked patient-level data on around 23.4 million people with short delays from vaccine administration to analysis • Figures include ~6.5 Million vaccinated by 24 February 2021	• Data from 40% of general practices that use TPP electronic health record software • Data from first weeks of rollout • Detailed discussion of data caveats elsewhere[23]	High quality Large 6.5 million sample
ONS Opinions and Lifestyle Survey	Cross-sectional representative survey data	• recent, timely • targeted, relevant questions • sufficient sample size for stratified analyses • sampling and weighting strategies to alleviate bias • accurate, reliable, high quality questionnaire • 72% response rate	• only available in Great Britain • data for Scotland and Wales cannot be analysed at same level of granularity as for English regions • due to broad coverage of topics, depth sometimes limited	High quality Representative, large survey with weighting used to compensate for non-response and under-coverage. Some interactions have smaller cell sizes and where relevant, noted to interpret with caution

				All estimates are shown with relevant confidence intervals and standard errors
[COVID-19 Infection Study (CIS)]	Repeated cross-sectional household survey with serial sampling and longitudinal follow-up	• recent, timely • sufficient sample size for stratified analyses • sampling and weighting strategies to alleviate bias • accurate, reliable, high quality questionnaire • individual and household data	• limited behavioural questions • limited and short questionnaire	High quality Representative, large survey with weighting used to compensate for non-response and under-coverage. Some interactions have smaller cell sizes and where relevant, noted to interpret with caution All estimates are shown with relevant confidence intervals and standard errors Given a smaller sample for the stricter lockdown 2 period, we may have limited power to detect some effects.
[Over 80s Vaccines Insights Study]		• recent, timely • nationally representative sample of over 80s in England • rare UK & international data on COVID-19 vaccine uptake, NPIs and related data •	• first time survey has been conducted and therefore graded by ONS as experimental statistics • sample only in England • response rate: of respondents successfully contacted by interviewer 56.5%; when including cases where contact was attempted but not made, 36.6%	Medium to High quality Representative, reasonably large (N=2,070) survey of over 80s, with results shown here based on weighted counts to compensate adjusted to address, age, sex and regional bias responses.

CKDelta mobile phone location data	Call detail records based event study	• beyond self-reported data • close to an RCT experimental design • near real-time measurement data • large initial data set, covering tens of millions of users - this made it possible to apply many filters to the data and still retain a high sample size for treatment group • data contain demographic information on users (age and gender) • timestamped travel patterns of individuals with an accuracy within a few km	• cell phone data are noisy, and mobility measures can have high variation • data do not represent individuals who do not use mobile phones (or use them rarely) • there are false positives and false negatives in our treatment group, but the anonymization of the dataset makes it impossible to know the magnitude of this • only able to analyse mobility patterns over a single calendar month	Medium to high quality Call detail records are representative, insofar as they cover a large share of the population (CKDelta covers around 10% of the British population). Classifications of vaccinated based on conservative assumptions, but sensitivity checks were conducted Data taken for a period of one month February and subject to roll-out eligibility and geographical differences

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