Nationwide demonstration of improved COVID-19 vaccination uptake through behavioural reminders

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Abstract

In this paper, we report the results of two nationwide randomised controlled trials (RCTs). By refining behavioural science-informed text messages notifying patients of their vaccine eligibility, we observed improvements in vaccination rates. The RCTs involved adults aged 40-44 (n=1,825,937) and 24-29 (n=2,506,004) in England. Messages emphasising "Top of queue" status led to small, but policy-relevant, increases in vaccination rates in the both the 40-44 age group (OR=1.02, 95% CI 1.01-1.03) and in the 24-29 age group (OR=1.02, 95% CI 1·01-1·04). Consequently, the "Top of queue" message was nationally rolled out to other age groups. These findings demonstrate the potential of “queue” framing in relevant contexts and the value of rigorous testing of public health messaging.

Introduction

Vaccination is a global public health priority. Where vaccines are available, timely uptake amongst eligible populations is critical to ensure a quick and effective rollout. Here we present the results from two population-wide randomised controlled trials (RCTs), in which we show that changes to the wording of behavioural science-informed messages notifying patients about their vaccine eligibility can increase COVID-19 vaccine uptake at a national scale.

Providing vaccination reminder messages has been shown to increase receipt of vaccination[1] and changing the content of reminders is a near costless intervention that can produce policy-relevant benefits across a range of behaviours.[2-4] Where vaccines are available and affordable, their timely uptake is critical and this was widely considered the most effective strategy for ending the COVID-19 pandemic.[5]

Prior behavioural science research suggests three main approaches to increasing vaccine uptake. The first two approaches involve interventions that aim to address how people think and feel about vaccines (their attitudes) or wider social processes, which jointly determine people’s motivations and intentions towards vaccination.[6] The third approach involves building on existing favourable intentions towards vaccination through interventions that facilitate vaccination directly, without aiming to change what people think and feel.[6] These interventions aim to address the gap between intentions and actions which is often observed across a range of behaviours, including vaccination.[7-9] Strategies to address this intention-behaviour gap typically aim to bring favourable intentions to front of mind through reminders and prompts, or by reducing practical barriers (for example through convenient logistical arrangements).[6] Effective behavioural strategies to increase vaccine uptake have included financial incentives,[10-11] default appointment scheduling,[12-13] and planning prompts,[14] as well as reminder and recall messages.[1] While the focus of many of these successful interventions is on closing the intention-behaviour gap, some also aim to change attitudes or social processes. It is important to recognise that while placing interventions into distinct categories has its

advantages, it is likely that most interventions will have a level of overlap within the different categories.

The literature defines reminders as notification that vaccination is due (because of age or other risk factors), while notifications that vaccination is overdue are referred to as recalls.[1,15] Providing reminder or recall messages has been shown to increase receipt of vaccination across a range of different modes of delivery (including e-mails, postcards, letters, text messages, and phone calls), populations, and vaccines.[1] The effectiveness of reminder and recall systems depends on several factors. These include systemic and logistical factors such as access to vaccinations, the accuracy of contact information and vaccination records, people's vaccination intentions, and to what extent messages are readable and comprehensible.[16-19] Messages are more effective when delivered by a familiar and trusted messenger, and should provide information about eligibility and how to take action.[20,21] Given the promise of reminder and recall messages as an intervention tool, there has recently been growing interest in the potential to further improve their effectiveness by applying behavioural science insights to optimise message content.[18] In particular, messages that prime a sense of ownership of the vaccine by stating that '[a dose] has been reserved for you' have been shown to be effective at increasing uptake.[3, 22-23]

In England, text messages became the primary mode of communication for health services to inform the population of their COVID-19 vaccine eligibility, ahead of letters. In line with the academic literature, this study refers to these messages as reminders, even if they constitute the first time patients are contacted directly about receiving the vaccine.[24] Timely response to these messages was a core dependency in the nation's vaccine rollout. Therefore, there was a pressing need to understand if the messages being sent out could be improved to increase timely vaccine appointment booking and vaccination uptake.[25] The findings of the studies had immediate practical implications for the vaccine rollout in terms of informing the ongoing rollout. It also constituted a unique opportunity to understand what messages worked best at the national level, contributing to the literature by providing insight into the effect of behavioural reminders (both those based on effective messages in prior research and those not previously studied) when they are scaled up across all patients.

To fill this gap, we undertook two multi-arm randomised controlled trials at national scale to test whether behaviourally-informed content in reminder text messages could increase timely booking and receipt of COVID-19 vaccination in England. Furthermore, we were interested in making sure that messages would not backfire and sizeably reduce booking and vaccination receipt rates among people belonging to ethnic groups with relatively low uptake rates (results reported in the Supplementary Information).

Results

Eligible participants were individually randomly assigned to be sent one of several text messages inviting them to book their COVID-19 vaccination. Following advice from the Joint Committee on Vaccination and Immunisation, NHS England sequentially opened eligibility to

vaccination for people in different age groups, from oldest to youngest in yearly birth cohorts in a staggered fashion.[26]

More detailed information about the study eligibility criteria, data collection, and randomisation procedures is available in the Methods section and in the Supplementary Information.

Study 1 - cohort aged 40-44

The first trial involved 1,825,937 eligible adults living in England. This corresponds to the full population of NHS patients (i) aged 40-44 (and those aged 39 who were due to turn 40 before 1 July 2021) recorded in the National Immunisation Management System (NIMS); (ii) with a valid mobile phone number; (iii) who had not already received or been invited for the COVID-19 vaccine via NIMS at the time of the study.

The intervention consisted of a text message reminder inviting participants to book their COVID-19 vaccination. In the first trial we developed eight text messages, applying a variety of different insights from behavioural sciences (see Table 1). The "Control" text message only included a simple statement about eligibility alongside the informational component. The "Simple" version was identical to the "Control" message, apart from replacing the term "eligible" with simpler wording ("you can now book") to make the message more accessible. The "Reserved" message built on previous research which found that reminders for flu vaccination were most effective when framed as reminders to get a vaccine that was already reserved for the patient.[3, 22-23] The "Top of queue" message presumed participants already wanted to get vaccinated and framed the opportunity as a privilege, drawing on evidence on the effectiveness of presumptive announcements for vaccination (see Brewer and colleagues[6]) and emphasising the scarcity and desirability of vaccination.[27] The message also highlighted that participants were a priority for vaccination. The "Join the millions" version leveraged the emerging social norm of getting the coronavirus vaccine in the UK.[28,29] The "Convenience" version sought to reassure participants that they could choose when and where to receive their vaccine (addressing a practical barrier to vaccination).[6] The "Protection against virus" version highlighted the personal health benefits of getting vaccinated, whereas the "Protect you and those close to you" version emphasised both the personal and collective health benefits of doing so.[30]

Effect on vaccination uptake - study 1

In the "Control" condition the vaccination rate was 27.31% (95% CI 27.13-27.49%). Compared with the "Control" message, the "Top of queue" message increased the vaccination rate by 0.38 pp or 857 people. The OR for the difference between the messages was 1.02 (95% CI 1.01-1.03, p = 0.0353 adjusted for multiple comparisons using the Benjamini-Hochberg procedure). The use of the Bonferroni-Hochberg procedure is pre-registered. Vaccination rates for groups that were sent the other six messages were not statistically significantly different from the control group at the conventional 0.05 significance level (see Figure 1 and Supplementary Table 5 in the Supplementary Information). We observe the second largest treatment effect for the "Convenience" message, though this is only significant at the 0.1 significance level, increasing the vaccination rate compared to the control by 0.30 pp or 684 people (OR 1.02

[95% CI 1-1.03], p = 0.0877 adjusted for multiple comparisons using the Benjamini-Hochberg procedure).

Study 2 - cohort aged 24-29

Overall, the second trial was similar to the first one in study design and general procedure, but differed in sample characteristics, message content, and the procedure of sending text message reminders. Study 2 involved 2,174,064 eligible adults living in England, corresponding to the population of NHS patients aged 24-29 (and those aged 23 who were due to turn 24 years old before 1 July 2021) recorded in the National Immunisation Management System (NIMS) and who had not already received or been invited for the COVID-19 vaccine via NIMS at the time of the study.

The intervention for study 2 was iterated based on that of study 1 (see Table 2). We used the same "Control" message to make findings from the two studies comparable. We removed the four relatively weak messages from study 1 but kept the three top performers — the "Top of the queue", "Reserved", and "Convenience" messages and added two hybrid messages combining the "Convenience" element with the "Top of the queue" and "Reserved" elements respectively. We also added the "Front of the queue" message as a variant of the "Top of the queue" message.

Effect on vaccination uptake - study 2

All messages with the "queue" element led to a significant increase in the vaccination rate. In the group that was sent the "Control" message, the vaccination rate was 23·68% (95% CI 23·52-23·83%). The "Top of the queue" message led to an increase in the vaccination rate by 0·41pp (or 1,219 people), corresponding to an OR of 1·02 (95% CI (1·01-1·04), $p < 0·001$ adjusted for multiple comparisons using the Benjamini-Hochberg procedure). The "Top of queue + Convenience" message was qualitatively the best performer, leading to a significant increase in the vaccination rate by 0.50 pp or 1,499 people. Paired comparisons among treatment arms were not conducted as they were not pre-registered. The odds ratio (OR) for the difference between the best-performing "queue" themed message and the control was 1.03 (95% CI (1.02-1.04), $p < 0.001$ adjusted for multiple comparisons using the Benjamini-Hochberg procedure). Lastly, the rephrased "Front of the queue" message led to a 0.36 pp (or 1,070 people) increase in the vaccination rate (corresponding to an OR of 1.02, 95% CI (1.01-1.03), p = 0.0028 adjusted for multiple comparisons using the Benjamini-Hochberg procedure). (See Figure 2 and Supplementary Table 12 in the Supplementary Information for more details).

Effect on vaccination booking rates

While the ultimate outcome of interest in this study was vaccination uptake, the primary outcome of this study was the vaccination booking rate, through the NHS National Booking System, within 72 hours of text messages being sent. This was originally chosen as the primary outcome, as very rapid information on the messages' possible effectiveness was required to inform the ongoing vaccine rollout. Across both trials the results for the booking rate outcome are in line with the findings for the vaccination rate, with messages including a "queue"

component leading to statistically significant increases in the booking rate. Full results of the messages' effect on vaccination booking rates are presented in the Supplementary Information.

Discussion

Our studies show that changing the wording of existing text message reminders can increase prompt booking and receipt of COVID-19 vaccination at minimal cost and national scale. Taking into account differences between these studies and previous studies, the treatment effects we observe are comparable with the small but policy-relevant increase in vaccination rates found in other studies which alter text message reminder content to increase vaccination uptake.[3,4,22,23] Upon completion of the study, the "Top of queue" message was rolled out nationally to people in England aged 30-37 (part of cohort 11, as determined by the Joint Committee for Vaccination and Immunisation) who were invited to receive their COVID-19 vaccination between May 18th and 27th 2021 (n = 4.7 million). (Note: Results from this trial were not yet available to inform the text messages sent to the first two years of COVID-19 vaccination cohort 11, e.g. 38 and 39 year olds). Following the results of study 2, the "Top of the queue" message was further rolled out to people aged 18-24 (n = 2.5 million). Reasonably assuming the message was similarly effective in cohort 30-37 and 18-24 as it was in our studies (there are no obvious *a priori* reasons why it would not be), we calculate that this will have led to an additional 42,000 [95% CI: 23,000, 61,000] first-dose COVID-19 vaccinations being received in these cohorts within 14 days of being sent this reminder text message, compared to if they had been sent the "Control" message. After applying the James-Stein estimator to mitigate for the effects of the 'winner's curse', this estimate decreases to 33,000.

Our studies have several substantial strengths, including their national-scale sample and the replication of results in two studies, providing very high external validity. This allows us to provide insight into the effect of reminders when they are scaled up across all patients, which makes the findings relevant to policy makers.[1,4] In particular, while the treatment effects we observe are small, this is not necessarily a limitation of the studies. Given their national scale, these studies provide a valuable contribution to the literature by giving a realistic benchmark for the effect that small changes to wording can have on behaviour when scaled up nationally. With a combined sample size of more than 4 million patients these are also among the largest individual-level RCTs that have ever been conducted in the field of behavioural science.

There are several possible explanations for the small effect size that was observed. It is likely that strong vaccination intentions, easy access to vaccines, and a behaviourally informed control text message contributed to the study's results. At the start of the pandemic period, 71.7% of adults in the UK were willing to receive a COVID-19 vaccine, a number which grew to over 90% in 2021, indicating the predominantly strong positive sentiments towards an easily accessible vaccine.[28] It is then likely that a behaviourally informed "top of queue" text message led to a small but detectable positive impact on whether adults in the UK received their vaccination over the two week period following their text reminder. Considering this context, it is further possible that there were fewer opportunities to change behaviours as compared to a vaccine hesitant population where there would be increased scope to effect behaviour change. Additionally, as the control group included a text message rather than the 'no message' control

condition other studies have reported, it is likely that this might have impacted on the observed effect.

Our trials also contribute to the literature by uncovering evidence for a behavioural approach to messaging in a health context that had not been investigated before (i.e. the successful message noting that people had reached the "top of the queue" - a finding from our first study which was replicated in our second study). Considering the underlying mechanisms for this original "Top of queue" message is particularly interesting, drawing on several findings from the behavioural science literature on vaccination. The first potential mechanism builds on existing evidence on the effectiveness of presumptive announcements - presenting vaccination as the default.[6] Informing people that they have reached the top of the queue implicitly assumes that they have indeed been queuing and want to receive the vaccine. The existence of a queue also emphasises scarcity and provides a signal about the social desirability of vaccination.[27] The message also informed people that they were now a priority, conveying a further sense of exclusivity and scarcity. Our studies also generate meaningful new insights in finding that messages which had been found to be effective in previous studies (e.g. those with "reserved" framing) did not produce a statistically significant effect beyond the control message. This also has practical implications: ex-ante, policymakers would have been inclined to choose a message that had performed well in previous studies rather than a new, untested message.

Our studies address a global public health priority — increasing vaccine uptake in a pandemic context — and use high-quality routinely collected administrative data on vaccination (not self-reported or intended vaccination), demonstrating clear and immediate health benefits from increased vaccine uptake. The intervention tested is scalable and the most effective text message intervention has already been implemented at scale following the trial, with further potential for scaling and generalising the findings of our studies.

They took place in a live policy environment with many different communications aimed at increasing vaccine uptake (including through broadcast media, national and local public health campaigns, and targeted local interventions including communications from General Practices and Clinical Commissioning Groups). Given the multitude of different messages participants in our studies were likely to receive, it is striking that small changes in the wording of the reminder text message led to small, but policy relevant changes in both booking rates and vaccination rates. This is particularly noteworthy given that we did not include a "no-message" control group in our studies. As the status quo before our studies involved sending a text message reminder to patients eligible for COVID-19 vaccination, we believed a "no-message" control would have been unethical, especially considering the strong existing evidence base for sending text message reminders compared with no reminder. It is also worth noting that the "Control" text message in our studies included several components that we believe are likely to contribute to its effectiveness (all messages, including the control, were relatively short, were from a trusted messenger, emphasised that the vaccine was free, and shared a common final sentence which consisted of a clear call to action and instructions on how to make a booking, with a hyperlink and phone number included). This allows us to isolate the effect of specific, small changes to the text message content, compared to a well-designed control message.

The studies also have several limitations. Given the nature of the intervention, including the large sample size and individual-level randomisation, there is a risk of contamination between experimental groups. It is possible that participants assigned to different treatment arms in the trial compared messages with people they know who received different messages (either directly or through social media). We expect that these kinds of spillovers would likely reduce the treatment effect we observe in our studies, so that these would be an underestimate of the effect we might expect in the absence of such spillovers (as those who received a more effective text message might have spread the word to encourage others — who may have received a less effective message — to receive their vaccination). While we did observe a positive impact of the "top of the queue" message, it is important to recognise that this phrasing may have been particularly effective in a population with predominantly positive vaccination attitudes and in a country with a widespread vaccination rollout.

Given the pandemic context and the nature of the vaccine rollout in England, our studies were designed to rapidly inform policy decision making regarding the content of text message reminders sent to younger cohorts following our trial. Therefore, our outcome measures focus on relatively short time horizons (including vaccination within 14 days). Although observing vaccination rates in the longer term would also be interesting, the objective of these studies was not only to generate rapid results, but also specifically to increase vaccinations quickly in the short term, given the expected health benefits from rapid vaccine rollout in the COVID-19 pandemic context. As noted above, the best-performing message in these studies has already been implemented as the new business-as-usual process following our trial. However, we are aware that this message, highlighting that people have reached the "top of the queue" may be particularly effective in the English context where eligibility for vaccination was extended in a stepwise manner according to clearly defined priority groups. Countries across the globe have differed in their approach to rolling out COVID-19 vaccines and the "top of queue" phrasing and context may be less relevant elsewhere (for example, we recognise that "queue" is British English and there is a recognised culture around queuing with its associated social norms). It is worth noting that enthusiasm for COVID-19 vaccination was particularly high in Great Britain, with more than nine in ten adults reporting positive sentiment towards COVID-19 vaccination during the study period.[28] Given this, it is likely that many of our study participants could relate to the feeling that they had indeed been in a queue to receive a vaccine. However, considering these positive sentiments towards vaccination, it is remarkable that small changes to the text message reminder content produced policy-relevant increases in both bookings and vaccination rates.

Further research is needed to investigate whether the "top of queue" message could be effective in other contexts, including outside of a context of vaccine scarcity. It is worth noting that relative vaccine scarcity and prioritisation is not limited to the COVID-19 pandemic context studied. Since our studies took place there has been similar scarcity in the UK during the rollout of the Monkeypox vaccine, and seasonal influenza and COVID-19 boosters have been prioritised for specific groups based on age and other risk factors.[31,32] Furthermore, vaccine supply problems are common in many low-income and middle-income countries.[33] An interesting line of enquiry for future research would be to test a similar message outside of the

vaccine context, but in a similar scarcity context. This could be a promising approach for other treatments or healthcare services in resource-constrained contexts where demand exceeds supply. For example, where patients have been waiting for appointments or treatments, this kind of message could be effective. Additionally, as it was outside the scope of this paper to comprehensively study how reminder messages work in population groups with relatively low uptake rates, it would be valuable to explore this topic in further detail.

It is worth noting that some of the literature on behavioural science and vaccine uptake using message reminders has reported mixed evidence. This may raise questions about the value that behavioural interventions add to the effectiveness of vaccine reminders; however, the varying results may be accounted for by the sample and methodology differences reported in the published literature. As such, while it is important to employ a critical lens to the evidence base, we argue that behavioural science-based interventions can add unique insights to current public policy approaches.

Finally, we believe this study and its findings make a compelling case for careful design and further rigorous testing of patient-focused communications and public health messaging in particular.

Methods

Ethical approval

We assert that all procedures contributing to this work comply with the ethical standards of the relevant committees. Study 1 received ethical approval from the NHS Health Research Authority (South West – Cornwall & Plymouth Research Ethics Committee) on April 21, 2021. REC reference: 21/SW/0055. Study 2 received ethical approval from the NHS Health Research Authority (South West – Cornwall & Plymouth Research Ethics Committee) on June 2, 2022. REC reference: 21/SW/0055. In both cases the committees accepted that the studies would not seek participants' informed consent. Seeking informed consent would have been disproportionate to the interventions tested, difficult and costly to implement, and would have potentially affected the validity of the studies' findings.

Trial methods summary

We undertook two multi-arm randomised controlled trials at national scale to test whether behaviourally-informed content in reminder text messages could increase timely booking and receipt of COVID-19 vaccination in England. Furthermore, we were interested in ensuring that messages would not backfire and lead to sizeable decreases in booking and vaccination receipt rates among people belonging to ethnic groups with relatively low uptake rates.

Eligible participants were individually randomly assigned to be sent one of several text messages inviting them to book their COVID-19 vaccination. Following advice from the Joint Committee on Vaccination and Immunisation, NHS England sequentially opened eligibility to vaccination for people in different age groups, from oldest to youngest in yearly birth cohorts in a staggered fashion.[26]

More detailed information about the study eligibility criteria, data collection, and randomisation procedures is available in the Methods section of the Supplementary Information.

The intervention consisted of a text message reminder inviting participants to book their COVID-19 vaccination. The themes and content of the text messages were developed by the study investigators in collaboration with staff at NHS England and NHS Improvement, as well as Public Health England (now UK Health Security Agency).

In each trial we developed several text messages, applying a variety of different insights from behavioural sciences. All text messages were sent from "NHSvaccine" and referred to the "NHS Covid-19 vaccine" since the literature suggests that using a familiar and trusted messenger can increase the efficacy of reminders.[20] The messages all communicated the recipient's eligibility for the vaccine and noted that the vaccine was free of charge. In addition, they all shared a common final sentence which consisted of a clear call to action and instructions on how to act, including a direct hyperlink to the National Booking System website to facilitate booking ("Please book yours now at https://nhs.uk/covid-vaccination [henceforth shortened to [LINK]] or by calling 119").

Both trials were pragmatic, parallel, single-blinded randomised controlled trials (the analysis was not performed blind to the randomisation allocation).

Outcomes

The primary outcome was the proportion of first dose vaccination appointments booked through the NHS National Booking System within 72 hours (inclusive) of the text message being sent (i.e. booking rate within 72 hours). This outcome was prioritised over the vaccination rate, as it was observed closer in time to the intervention, and enabled faster policy decision-making. The 72-hour window was chosen because this was when most bookings had occurred in the previous age cohort (at the time of the study 90% of bookings made by 55-year-olds had been made in the three days after the text message reminders informing them of their eligibility had been sent).

The secondary outcome was the proportion of first dose vaccinations received within 14 days (inclusive) of the text message being sent (i.e. vaccination rate within 14 days). The period of 14 days was calculated at the level of days rather than hours. This timeframe was chosen as many first dose vaccination appointments were bookable within this timeframe at the time reminders were sent, increasing uptake in the short term was a public health and policy priority, and rapid outcome information was needed to inform decisions on the content of reminders to subsequent age cohorts. More information on the power calculations and analytical methods is available in the Supplementary Information.

Study 1 - cohort aged 40-44

The first trial involved 1,825,937 eligible adults living in England. This corresponds to the full population of NHS patients (i) aged 40-44 (and those aged 39 who were due to turn 40 before 1 July 2021) recorded in the National Immunisation Management System (NIMS); (ii) with a

valid mobile phone number; (iii) who had not already received or been invited for the COVID-19 vaccine via NIMS at the time of the study.

On Monday April 26th, NHS patients aged 44 years old became eligible for the COVID-19 vaccine and were sent a text message invitation, followed by NHS patients aged 43 and 42 years on Tuesday April 27th and by NHS patients aged 41 and 40 years on Friday April 30th. (Note: each of these age groups also contains individuals who were due to turn that age before 1 July 2021). They were also sent a standard letter invitation from the NHS which they would be expected to receive around three to five business days after the text message reminders were sent.

Procedures - study 1

The intervention consisted of a text message reminder inviting participants to book their COVID-19 vaccination. In the first trial we developed eight text messages, applying a variety of different insights from behavioural sciences (see Table 1). A more detailed description of the text messages can be found in the results section above.

Participants were recruited between April 26th and April 30th, 2021. A total of 2,514,566 adults aged 40 to 44 years old in England who had not been invited to book a COVID-19 vaccination appointment via the NHS National Booking System were assessed for eligibility. Of these, 688,629 did not meet eligibility criteria (due to invalid mobile numbers or system errors - see Figure 3), resulting in a final sample of 1,825,937. These participants were randomly assigned to control (n = 228,232) or one of seven treatment groups (n = 227,718 - 228,930). Participants' vaccination records were collected in the NHS National Immunisation Management Service (NIMS) database and were included in the primary analysis. A summary of participants' demographic characteristics by randomisation condition is provided in the Supplementary Information (Supplementary Table 3).

We estimated that this sample size was large enough to be able to observe a 0.4 percentage point change in the vaccination booking rate within 72 hours with 80% power (using the Bonferroni method to adjust for multiple comparisons, as a conservative approach to estimating power) among the general population. The large sample size also meant that the study was powered to detect a reasonably small but important backfire of 2 percentage points among specific ethnic groups characterised by low vaccination rates, were such effects real. All statistical tests (including hypothesis testing for power calculations) were two-tailed.

Study 2 - cohort aged 24-29

Overall, the second trial was similar to the first one in study design and general procedure, but differed in sample characteristics and the procedure of sending text message reminders, and iterated the intervention text messages based on insights gained from study 1. Study 2 involved 2,174,064 eligible adults living in England, corresponding to the population of NHS patients aged 24-29 (and those aged 23 who were due to turn 24 years old before 1 July 2021) recorded in the National Immunisation Management System (NIMS) and who had not already received or been invited for the COVID-19 vaccine via NIMS at the time of the study.

Procedures - study 2

Participants were recruited between June 8th and June 12th, 2021. A total of 2,545,398 adults aged 24 to 29 years old in England recorded in NIMS were assessed for the study inclusion criteria. Of those, 2,174,064 met the inclusion criteria (see Figure 4). These participants were randomly assigned either to the control group (n = 357,901) or to one of six treatment groups (n = 256,085 - 359,378). Unlike in study 1, where eligibility for the NHS COVID-19 vaccine was staggered by year group within the study cohort (e.g. participants received their SMS invitation on the day they became eligible to receive the vaccine), all participants in study 2 became eligible for vaccination on the first day of study 2, while text message invitations were staggered over several days by age within the study cohort. This resulted in 13.2% of the eligible sample (n = 331,940) booking a vaccination appointment before being sent an invitation SMS. After excluding those participants, the final sample included 2,174,064 participants. Participants' vaccination records were also collected in the NIMS database and were included in the primary analysis. A summary of the sample characteristics by experimental condition is presented in the Supplementary Information (Supplementary Table 10).

The sample size achieved meant that we were be able to observe (i) a 0.3 percentage point change in the vaccination booking rate within 72 hours among the general population; and (ii) and a 2 percentage point change among the ethnic groups analysed (with 80% power, using the Bonferroni method to adjust for multiple comparisons, as a conservative approach to estimating power).

The intervention for study 2 was iterated based on that of study 1 (see Table 2). We used the same "Control" message to make findings from the two studies comparable. We removed the four relatively weak messages from study 1 but kept the three top performers — the "Top of the queue", "Reserved", and "Convenience" messages and added two hybrid messages combining the "Convenience" element with the "Top of the queue" and "Reserved" elements respectively. We also added the "Front of the queue" message as a variant of the "Top of the queue" message.

Protocol registration

All exclusion criteria and analyses were pre-registered (study 1 was pre-registered at OSF: https://osf.io/e4856; study 2 was pre-registered at ISRCTN: https://doi.org/10.1186/ISRCTN15317247). In addition, as study 1 was pre-registered in a non-clinical trial registry, study 1 was also retroactively registered on clinicaltrials.gov: (Identifier: NCT05993260).

Data availability statement

The study protocol is provided in the appendix. All data requests should be submitted to NHS England and NHS Improvement (the data controller) for consideration. Access to the raw anonymised data may be granted for non-commercial research at the discretion of NHS England and NHS Improvement. Further information can be obtained from the corresponding author at hannah.behrendt@bi.team.

Code availability statement

Custom code that supports the findings of this study is available from the corresponding author upon request.

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Author contributions

HB, GT, YX, HH, NG, DW, RR, RS conceived the study and contributed to the study design. HB, GT, YX developed the trial protocol. HB, GT were responsible for the study implementation and project management for study 1 and 2. GT, LT, YX conducted the statistical analysis for study 1. GT, YX conducted the statistical analysis for study 1. HB, GT, LT, YX contributed to the interpretation of the data and the writing of the paper. All authors were responsible for editing and approving the paper.

Competing interests

The authors declare no competing interests.

Figures

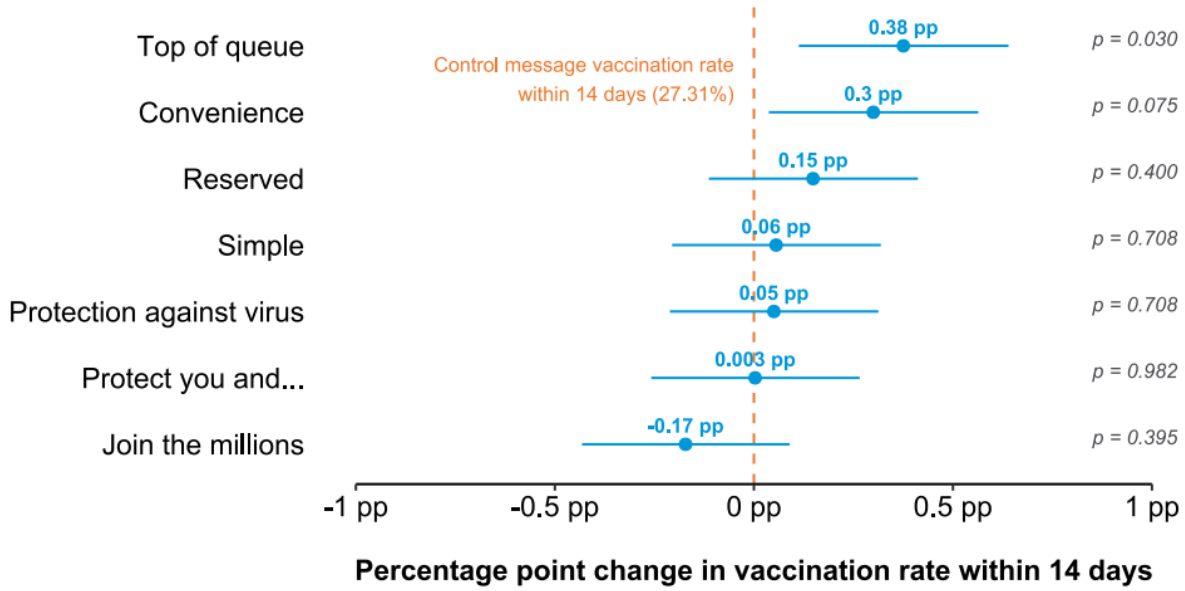

Figure 1: Adjusted percentage point change in vaccination rate within 14 days for each treatment text message reminder compared to control text message reminder in study 1, with 95% CIs. (Note: Sample size study 1 = 1,825,937. The "Control" message vaccination rate is unadjusted for covariates. 95% CIs are not adjusted for multiple comparisons, whereas p-values in the graph are adjusted for multiple comparisons using the Benjamini-Hochberg correction.)

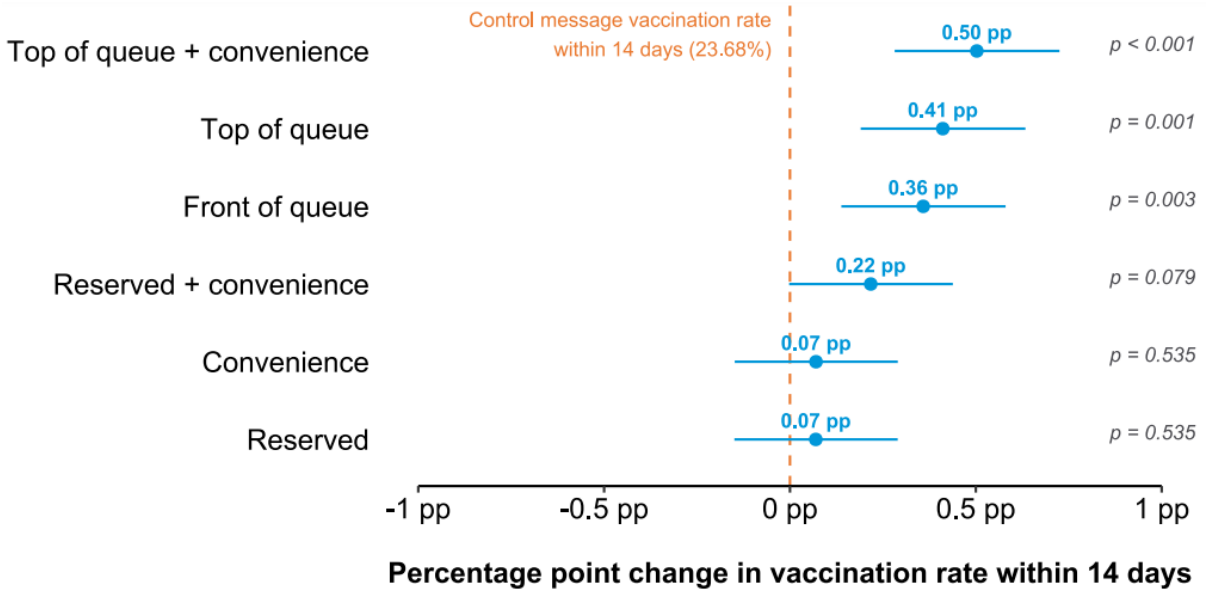

Figure 2: Adjusted percentage point change in vaccination rate within 14 days for each treatment text message reminder compared to control text message reminder in study 2, with 95% CIs. (Note Sample size study 2 = 2,506,004. The "Control" message vaccination rate is unadjusted for covariates. 95% CIs are not adjusted for multiple comparisons, whereas p-values in the graph are adjusted for multiple comparisons using the Benjamini-Hochberg correction.)

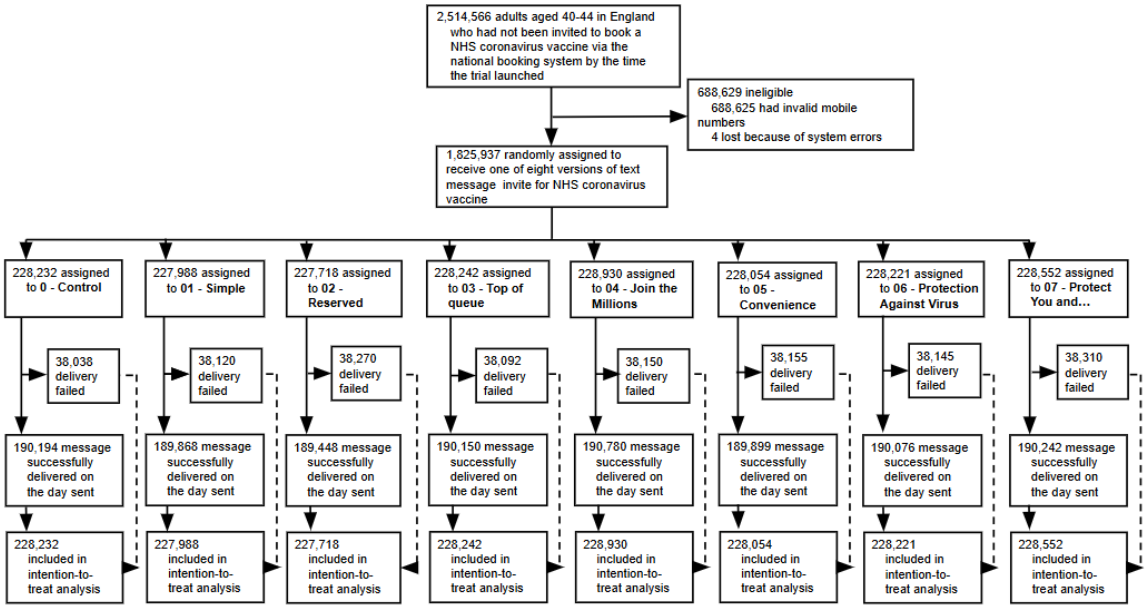

Figure 3: Trial profile for study 1

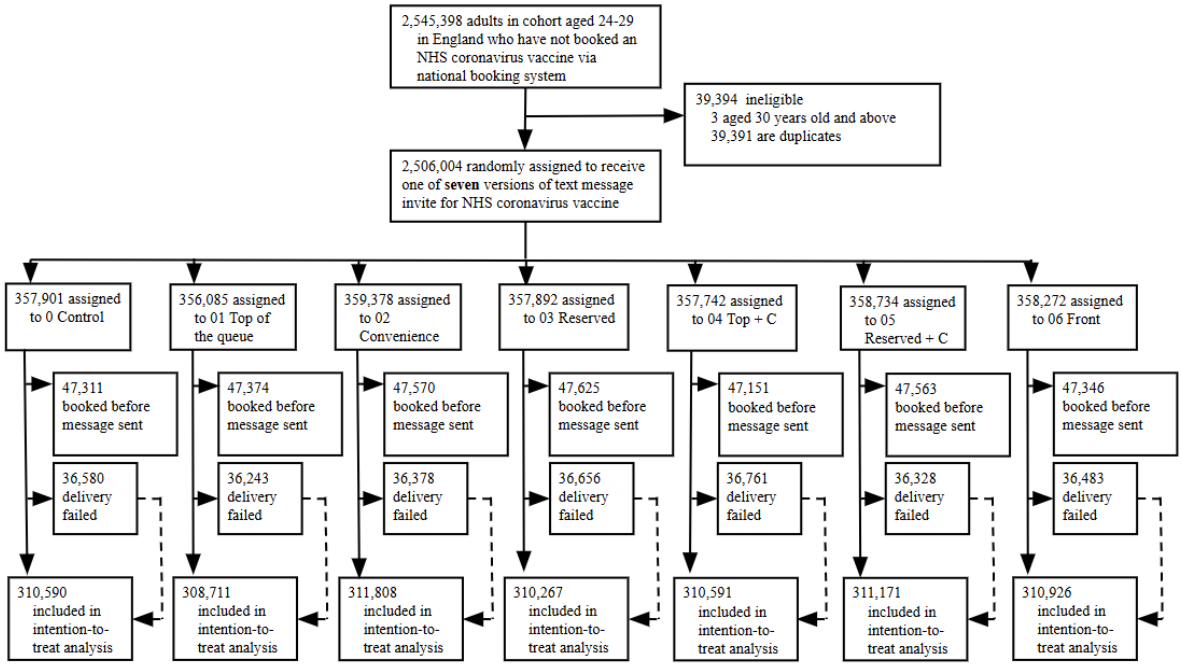

Figure 4: Trial profile for study 2

Tables

Table 1. Intervention text message reminders - study 1

Trial arm	Theme	Content
0	**Control**	You are now eligible for your free NHS Covid-19 vaccine. Please book yours now at [LINK] or by calling 119.
1	**Simple**	You can now book your free NHS Covid-19 vaccine. Please book yours now at [LINK] or by calling 119.
2	**Reserved**	Your free NHS Covid-19 vaccine is waiting for you. Please book yours now at [LINK] or by calling 119.
3	**Top of queue**	You've reached the top of the queue and are a priority for getting a free NHS Covid-19 vaccine. Please book yours now at [LINK] or by calling 119.
4	**Join the millions**	You are now eligible for your free NHS Covid-19 vaccine. Join the millions who have already had theirs. Please book yours now at [LINK] or by calling 119.
5	**Convenience**	You are now eligible for your free NHS Covid-19 vaccine. Choose a time and place that suits you. Please book yours now at [LINK] or by calling 119.
6	**Protection against virus**	You are now eligible for your free NHS Covid-19 vaccine. Getting vaccinated is the best protection against coronavirus. Please book yours now at [LINK] or by calling 119.

7	**Protect you and those close to you**	You are now eligible for your free NHS Covid-19 vaccine. Getting the vaccine is the best way to protect yourself and those close to you against coronavirus. Please book yours now at [LINK] or by calling 119.

Table 2. Control and intervention text message reminders - study 2

Trial arm	Theme	Content
0	**Control**	You are now eligible for your free NHS COVID-19 vaccine. Please book yours now at [LINK] or by calling 119.
1	**Top of queue**	You have reached the top of the queue and are a priority for getting a free NHS COVID-19 vaccine. Please book yours now at [LINK] or by calling 119.
2	**Convenience**	You are now eligible for your free NHS COVID-19 vaccine. Choose a time and place that suits you. Please book yours now at [LINK] or by calling 119.
3	**Reserved**	Your free NHS COVID-19 vaccine is waiting for you. Please book yours now at [LINK] or by calling 119.
4	**Top of queue + Convenience**	You have reached the top of the queue and are a priority for getting a free NHS COVID-19 vaccine. Please book yours now - choose a time and a place that suits you at [LINK] or by calling 119.
5	**Reserved + Convenience**	Your free NHS COVID-19 vaccine is waiting for you. Please book yours now - choose a time and a place that suits you at [LINK] or by calling 119.
6	**Front of queue**	You have reached the front of the queue and are a priority for getting a free NHS COVID-19 vaccine. Please book yours now at [LINK] or by calling 119.