Protocol

Interventions to increase vaccine uptake: Systematic review and component network meta-analysis to identify the most effective strategies

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Version	Date	Amendments
0.1	20 October 2022	
0.2	25 April 2023	- Restricted eligible study designs to (cluster) randomised controlled trials. - Clarified that studies targeting healthcare workers as the intended recipients of vaccinations are not eligible for inclusion. - Changed “We will characterise the features of interventions using the Communicate to Vaccinate taxonomy….” to “We will characterise the features of interventions based on the ‘5As’ – a practical taxonomy for the determinants of vaccine uptake.”

1. Background and scientific rationale

The COVID-19 pandemic has brought into sharp focus the potentially devastating impact of infectious diseases for individuals, societies and economies. Vaccines are an extremely powerful and highly cost-effective public health intervention to reduce morbidity and mortality (1). High vaccine uptake is critical for combatting infectious diseases, not only by protecting individuals but also promoting herd immunity (2). However, there have been concerning declines in the uptake of routine childhood vaccinations in the UK in recent years, exacerbated by the pandemic. The UK lost its 'measles-free' status in 2019, and in 2021 MMR vaccine coverage remained below the 95% target (3, 4). Measles cases have been rising rapidly in Europe, demonstrating how quickly potentially deadly childhood infections can resurge when vaccine coverage is sub-optimal (5).

Optimising vaccine provision is the first strategic priority in the Public Health England (now UK Health Security Agency) Infectious Diseases Strategy 2020-25 (6), but there are ongoing challenges in achieving and maintaining high vaccine uptake. Vaccine hesitancy (a delay in acceptance or refusal of vaccination despite availability of vaccination services) has been identified as one of the biggest threats to global health (7). Its key drivers are: 'Confidence' – e.g. lack of trust in the effectiveness and safety of vaccines; 'Complacency' – e.g. failure to appreciate the potential severity of some childhood diseases owing to reductions in the population due to vaccination programmes; and 'Convenience' - ease of access to vaccination services, a known barrier including in the UK (8, 9).

A wide range of interventions have been applied to increase vaccine uptake, including patient call/recall and reminders, education, media campaigns, improving access to vaccination and incentives. However, there are important gaps in the evidence around determining which interventions or features of interventions are most effective, in which population groups and contexts, and in identifying the 'active' components of multi-component interventions.

Interventions designed to increase vaccine uptake are typically complex, with multiple components, and standard approaches to evidence synthesis may not capture the complexity. Existing reviews on the topic conduct traditional pair-wise meta-analyses (10, 11). While useful to answer 'in principle' questions such as "are XX interventions effective compared with a single control/comparator", standard meta-analysis tends to lump different types of interventions together into broad categories and is not well able to address the complexity of interventions and the influence of the context in which they are applied.

We will use a component network meta-analysis approach. This allows the comparative effectiveness of multiple active interventions to be evaluated in a coherent way, enabling us to answer questions such as "which intervention, components or combination of components are most effective for XX?". This provides a more meaningful analysis of complex interventions and a nuanced evidence base with which public health practitioners can identify the most effective interventions for their specific population and context.

The pandemic has highlighted and widened health inequalities. COVID-19 vaccine uptake is lower in some population sub-groups e.g. ethnic minority groups and deprived communities (12), as is observed for other routine vaccinations (13, 14). It is crucial that we identify effective interventions that can address these inequalities so that tailored strategies can be applied to under-vaccinated groups. Working closely with stakeholders (including co-applicants Yates and Letley from the UK Health Security Agency), as a key objective we will identify which intervention components and packages work best for underserved communities who may have lower vaccine uptake. We will also consider the potential cost-effectiveness of strategies found to be effective. This will generate new knowledge and help enable improved local and adaptable intervention design, and the tailoring of interventions for specific communities, ensuring that the outputs of our work are valuable for informing policy and practice.

This work is relevant to: i) maintaining and enhancing routine vaccination programmes; ii) ensuring high levels of COVID-19 vaccine coverage in the coming years (if, as has been suggested, this becomes a seasonal vaccine); and iii) preparing for future infectious disease epidemics and pandemics.

Existing literature

Whilst there are numerous published reviews on the effectiveness of interventions to increase vaccine uptake, each addresses specific populations, vaccine types and/or interventions. Existing Cochrane reviews include those examining influenza vaccination uptake in older adults (11), and patient reminder and recall interventions (10). The National Institute for Health and Care Excellence (NICE) recently published a guideline 'Vaccine uptake in the general population' (15). Although this covers all populations eligible for vaccines on the UK routine immunisation schedule, the large body of evidence on seasonal vaccinations such as influenza is excluded. We are not aware of any high-quality reviews synthesising all the evidence on interventions targeting vaccine recipients (or their caregivers) to increase vaccine uptake. Bringing all the evidence together is highly relevant to the COVID-19 pandemic and other such future scenarios where new vaccines may be applied across the whole population, potentially seasonally. Importantly, the NICE evidence syntheses are not complex, for example, no network meta-analyses were conducted. Naïve syntheses may fail to pick up important differences between groups/contexts or to capitalise on similarities.

Based on studies included in existing published systematic reviews, we estimate the number of primary studies eligible for inclusion in our review is at least 250-300. This estimate is supported by the draft NICE evidence reviews which include 178 potentially relevant primary studies (searches conducted May 2021) (15). As noted, the NICE review excludes studies on influenza vaccine uptake, but other key systematic reviews indicate that the evidence base on influenza vaccines is sizable (e.g. the aforementioned 2018 Cochrane review on influenza vaccination uptake in older adults included 49 primary studies potentially eligible for inclusion in our evidence synthesis).

There has been a major increase in interest in the topic of vaccine uptake due to COVID-19. Of concern, however, a recent assessment of 88 systematic reviews on COVID-19 found nearly all (97%) were of poor quality (16). Meanwhile, a 2019 review on the quality of reporting in systematic reviews on interventions to increase vaccine uptake found that the mean percentage of applicable PRISMA items that were met across all studies was 66% (range 19-100%) (17). This demonstrates the need for robust and properly resourced evidence syntheses to ensure public health recommendations are based on reliable evidence.

With regard to the economic evidence, the NICE guideline 'Vaccine uptake in the general population' included 11 cost-utility or cost-effectiveness studies on reminder, education, multicomponent and financial incentive interventions (15). Existing reviews have reported notable variation in the costs of interventions (18-21). A wide range of factors will contribute to this variability in costs including the scope of the intervention, characteristics and components of the intervention, and the context in which the intervention is applied.

In summary, there is currently a gap between the available evidence base and the nuanced information required to identify and apply effective tailored interventions in practice. Bringing all the evidence together and conducting our unique synthesis will provide highly relevant and robust information to support vaccination programmes.

2. Research question

Our research aims to address the question “Which interventions, or components of interventions, are most effective in increasing vaccine uptake in high and upper-middle income countries?”

Our specific objectives are to:
1. Collate and appraise the evidence on interventions designed to increase vaccine uptake.
2. Synthesise the evidence to establish which interventions are most effective.
3. Explore variation in the effectiveness of interventions according to intervention features, type of vaccine, context and socio-demographic characteristics of the population to gain new insights.
4. Collate data on intervention costs and existing economic evaluations.

3. Methods

Review conduct

We will conduct a comprehensive systematic review guided by the Cochrane Handbook for Systematic Reviews of Interventions (22). The review protocol will be registered with PROSPERO (https://www.crd.york.ac.uk/prospero/). Reporting will follow the PRISMA guideline (23).

Eligibility criteria

Criteria for selecting studies for inclusion in the review are detailed below.

Types of vaccines: All universal and selective/targeted vaccinations on the UK immunisation schedule, including seasonal vaccinations such as influenza, but excluding travel vaccinations.

Participants: Studies on all population groups living in the community and eligible for vaccination (or carers of those eligible for vaccination), including parents of young children, adolescents and adults. Interventions targeting hospital inpatients, prisoners, and residents of care/nursing homes or other such residential institutions will be excluded. We will also exclude studies targeting healthcare workers as the intended recipients of vaccinations. Eligible studies are those with at least 100 participants at baseline.

Interventions: Based on the broad intervention categories used by the Community Preventive Services Task Force (24), we will include any type of intervention aimed at increasing demand for, or access to, vaccination. These comprise interventions targeting the intended recipients of vaccines or their caregivers. Such interventions may include, for example, communication, education, and information strategies delivered by any means (e.g. letters, leaflets, educational campaigns, mainstream and social media campaigns, vaccination campaigns) as well as patient reminders, recalls and incentives, and interventions designed to increase access via different delivery models such as ‘pop up’ clinics, home visits, specific sessions for underserved communities, or reducing bureaucracy (e.g. not needing to have an NHS number or be registered with a GP).

We will exclude provider- or system- based interventions (e.g. provider assessment and feedback, provider incentives). Studies applying multicomponent interventions aimed at both the intended recipients of vaccines and providers or systems will be excluded, unless effectiveness data is available for the component targeting the intended recipients of vaccines alone.

Comparators: Studies using comparator groups of no intervention, usual care, waitlist, attention placebo or an alternative eligible intervention will be included.

Outcome of interest: Vaccine uptake, including single vaccinations and/or completion of a full vaccination course, documented in medical records or self-reported. We will exclude studies only reporting on outcomes such as attitudes to vaccination and intention to vaccinate.

Types of studies: Randomised controlled trials (RCTs; cluster or individually randomised). Cluster RCTs must have at least three intervention sites and three control sites.

Context: We will include studies, published from 2000 onwards, undertaken in high and upper-middle income countries, as defined by the World Bank.

Search methods for identification of studies

A comprehensive two-stage search strategy will be developed built around existing high-quality systematic reviews on the topic. This will include two large Cochrane reviews (10, 11) and NICE evidence reviews (15, 25). Initially we will capture studies included in such systematic reviews. We will then organise these into high level themes/intervention types around which we will build a bespoke search strategy to capture studies not included in these existing reviews.

We will search the following electronic databases for reviews and primary studies: Cochrane Library Database of Systematic Reviews (CDSR); Cochrane Central Register of Controlled Trials (CENTRAL); Epistemonikos; Health Evidence (McMaster University); EPPI Centre Database of Promoting Health Effectiveness Reviews (DoPHER); EPPI Centre Database of Trials Register of Promoting Health Interventions (TRoPHI); NIHR Journals Library; MEDLINE ALL (Ovid); Embase (Ovid); PsycINFO (Ovid); Cumulative Index to Nursing and Allied Health (CINAHL) (EBSCOhost); British Education Index (EBSCOhost); Educational Resources Information Center (ERIC) (EBSCOhost); Sociological Abstracts (ProQuest). The electronic search strategy will be developed using a combination of Subject Headings (e.g. MeSH terms), keywords and search syntax appropriate to each resource. No language restrictions will be applied. We will also search for abstracts from key conferences such as Vaccine Congress.

We will search for grey literature (primarily theses) using: Open Grey; ProQuest Dissertations & Theses Global; DART-Europe E-theses Portal; British Libraries e-theses online service (EThOS); Networked Digital Library of Theses and Dissertations (NDLTD); Open Access Theses and Dissertations (OATD). We will also use the reference lists of eligible study reports as an additional source of relevant primary studies. Search hits will be managed in Endnote.

Selection of studies for inclusion

Following the deduplication of search hits in Endnote, all unique references will be imported into Covidence (https://www.covidence.org/). Screening will be conducted independently by two reviewers. Discrepancies will be resolved by discussion, with the involvement of a third reviewer as necessary. Reasons for exclusion at the full text screening stage will be documented using a pre-defined hierarchical list. Where more than one publication pertaining to the same study is identified we will use the most comprehensive as the main source, with additional information sought from associated publications as required.

Data extraction

Key data items (intervention characteristics and numeric data on outcomes) will be independently extracted by two reviewers using a pre-defined database. Other items will be extracted by one reviewer and checked for accuracy by a second. Data items that are already documented within existing high-quality systematic reviews (e.g. NICE or Cochrane reviews) will be extracted from the primary study report(s) by one reviewer and then compared with the data presented within the existing review. If any discrepancies are identified, the data item(s) will be checked by a second reviewer. Data items to be extracted will include study setting; study design; number of participants and participant characteristics (including socio-demographics); vaccine(s); intervention details including all components; population reach (i.e. number of people in the target population, or, in the case of trials, in the group that received the intervention), outcome specification (e.g. uptake of single vaccine

dose or completion of a vaccination course); method of outcome assessment; numeric data on the number of vaccinated and unvaccinated individuals in the intervention and comparator groups and reported effect estimates (unadjusted and adjusted) with 95% confidence intervals.

If a study reports outcome data at multiple time points we will use the primary outcome as specified by the authors of that study. Where studies report on both uptake of a first vaccine dose and completion of the full vaccination course both will be extracted. Where insufficient data are reported we will contact the study authors to request the required information with one reminder to non-responders.

Risk of bias

Risk of bias (RoB) will be assessed separately for different outcomes. Therefore, for example, for studies reporting on both uptake of a single vaccine dose and completion of a full vaccination course two risk of bias assessments will be carried out. Bias will be assessed using the Cochrane RoB 2 tool (26). Assessments will be conducted independently by two reviewers, except for studies that have already been assessed, using the RoB 2 tool, as part of existing high-quality systematic reviews (e.g. NICE or Cochrane reviews). For these, the assessment will be conducted by one reviewer using information provided in the primary study report(s) and then compared with the assessment presented in the existing review. If discrepancies are identified, the assessment will be checked by a second reviewer.

Confidence in the body of evidence

We will assess certainty in our findings broadly following the Confidence in Network Meta-Analysis (CINeMA) framework (27), which is based on GRADE (Grading of Recommendations, Assessment, Development and Evaluations) (28). The framework can be applied directly to standard and network meta-analysis through the CINeMA software. For component network meta-analysis, no comparable tool currently exists and we will adopt the CINeMA framework as a basis for reaching judgements outside of the CINeMA software.

Economic evidence

During data extraction, any studies reporting relevant cost and health economic information will be flagged. We will then extract information on intervention costs and any health economic evaluations of interventions (or components) that we find to be effective in increasing vaccine uptake. Additionally, we will specifically search for health economic evaluations of the interventions in our included studies that may have been reported on separately. This will include examining trial registrations and protocols of studies included in our systematic review to identify where an economic analysis was intended, and then locating these using forward citation searching. Relevant systematic reviews will also be examined.

Data items for extraction (where reported) will include: total cost of intervention, cost of intervention per person vaccinated (or raw data with which to estimate this), quality-adjusted life years (QALYS) and incremental cost-effectiveness ratios from both cost-utility and cost-effectiveness analyses. We will work with our stakeholders to develop a hierarchy for the extraction of these items to ensure that our outputs are useful for policy and practice. Quality of the economic evidence for each study will be assessed using the Drummond checklist (29).

Extracted data will be tabulated alongside information on intervention reach and effectiveness, stratified by e.g. intervention type and population group. Where reported we will collate intervention costs, incremental cost-effectiveness ratios and characteristics of any economic evaluations stratified by individual components and for the intervention overall.

We will be mindful that our reporting and interpretation of intervention effectiveness and associated costs does not have the potential to inadvertently cause any widening of inequalities. This could be the case if, for example, we find in our analyses that interventions that effectively optimise vaccine uptake in underserved groups are more costly than those targeting the wider population. To address this, we will also give consideration to whether the costs of any intervention might differ according to the target population, even if not directly reported on in the individual studies included in our synthesis.

The analytic framework

We have developed a preliminary logic model which will inform our analytical approach to evidence synthesis. Our analytic framework will incorporate the key characteristics of interventions and the context in which they are applied as well as the characteristics of the population. The framework will be further developed and refined through discussions with our stakeholders and patient and public involvement (PPI) group.

In developing our analytic framework we will consider in detail the determinants of vaccine hesitancy. These are complex and context specific, varying by time, place and specific vaccine. We will start by considering the three 'Cs' described earlier (confidence, complacency and convenience). Vaccine hesitancy is a behaviour resulting from a decision-making process. Any intervention to increase vaccine uptake may influence multiple determinants of hesitancy and ultimately aims to change people's behaviour. The development of our framework will thus be further informed by the SAGE Working Group on Vaccine Hesitancy 'Vaccine Hesitancy Determinants Matrix' which categorises the factors that influence the behavioural decision-making process around vaccination into three domains: (i) contextual influences (e.g. historic, socio-cultural, environmental, health system/institutional, economic or political factors); (ii) individual and group influences (e.g. personal perception of the vaccine or influences of the social/peer environment); and, (iii) vaccine and vaccination-specific issues that are directly related to the characteristics of the vaccine or the vaccination process (9, 30). Consideration of likely mechanisms of action of interventions to increase vaccine uptake will be underpinned by behaviour change theory.

Characterisation of the features of interventions

We will undertake a detailed examination of variability in intervention effectiveness according to intervention features, type of vaccine, context and socio-demographic characteristics of the population. We will characterise the features of interventions using the '5As' – a practical taxonomy for the determinants of vaccine uptake (31), adapting and supplementing this where necessary by co-producing de novo high-level coding of intervention features and contexts with input from experts, stakeholders and the public (particularly members of underserved communities) to identify which features are likely to be most important. We will determine which of these features can be accurately identified from the intervention descriptions, and draw as required on other existing taxonomies (e.g. Behaviour Change Techniques) (32), and theory (e.g. Protection Motivation Theory, Necessity-Concerns framework) (33, 34). Agreement on de novo coding will be achieved through discussions within our project team, who bring a diverse range of expertise and perspectives and includes UK Health Security Agency stakeholders, with our project collaborators who include further public health stakeholders (e.g. in local authorities) and with members of our PPI group. We will apply methods adapted from intervention development to integrate theory, evidence and expert, stakeholder and public perspectives (35, 36).

Evidence synthesis

We will prepare a statistical analysis plan prior to commencing our analyses.

Pair-wise and network meta-analyses

Our initial synthesis will involve a series of pair-wise and network meta-analyses to examine the broad intervention approaches individually and in comparison with others. For this initial synthesis we will group interventions at a high level, broadly following the themes/intervention types created as part of our search strategy. Odds ratios or risk ratios and 95% confidence intervals will be used (including adjusted estimates where reported) for each outcome reported in each study, where possible following an intention to treat approach. Where necessary, transformations between risk ratios and odds ratios will be implemented based on overall proportions of events. Where authors of cluster RCTs have not accounted for clustering in the analyses we will adjust for this using methods outlined in the Cochrane Handbook (22).

Pair-wise random-effects meta-analyses will be conducted using methods described in the Cochrane Handbook (22). Where heterogeneity is present this will be investigated with meta-regression techniques using a pre-defined set of explanatory variables (e.g. initially population group and vaccine type) which will be detailed in our statistical analysis plan.

We will perform network meta-analysis to allow the simultaneous comparison of multiple interventions in a single model. Analyses will be conducted within a Bayesian framework. Evidence of incoherence will be sought from a combination of node splitting and design-by-treatment interaction models (37, 38). Where there is evidence of incoherence, we will firstly check the data for potential data extraction errors that may contribute to this incoherence and correct any errors identified. We will next explore reasons for any incoherence using network meta-regression techniques, including potential effect modifiers as covariates (39).

(Component) network meta-analyses to explore variation in the effectiveness of interventions

We will use both network and component network meta-analysis models to explore interventions/components and aspects of context in detail. This will allow us to identify the (most) effective components or combination of components of interventions, and the population groups and contexts in which they are most effective.

Initially we will develop basic component network meta-analysis models which assume that intervention components have additive effects (i.e. that the effect of an intervention that comprises two components, A and B, is the sum of the effects of A and B) and there are no interactions between components. We will then extend the models to allow for interactions between components which may act synergistically or antagonistically thus resulting in either larger or smaller effects than the simple sum of their effects.

Variables for inclusion in our network and component network meta-analysis models will include coded components of intervention features and the context into which the intervention is introduced as well as the characteristics of the population. We use the term ‘context’ here to include ‘setting’ but cover a broader range of dimensions, as defined in the Craig *et al* guidance on taking account of context in population health intervention research (40). Example aspects of context that we will consider in our analyses include the geographical/environmental setting (e.g. high vs. upper-middle income countries; country; primary care; schools; wider community), social/economic (e.g. neighbourhood deprivation), and service/organisational (e.g. socialised vs. privatised health system). Recognizing the huge impact of the COVID-19 pandemic on the context into which interventions are introduced, we also plan to undertake sub-group analyses separating out studies conducted pre-pandemic and during/after the pandemic.

We will also investigate inequalities in the effectiveness of interventions. This will initially be done at the intervention level and where variations are identified we will further explore these within our

component network meta-analyses. We will consider all PROGRESS items (place of residence, race/ethnicity/culture/language, occupation, gender/sex, education, socio-economic status and social capital) for which we find meaningful data (41). We will examine whether the effects of interventions differ according to these characteristics. We will use data both from studies that specifically focus on these groups and those that provide a breakdown of the study population by socio-demographic characteristics. Where this information is not reported we will request it from the study authors. To address intersectional inequalities for marginalised groups with combinations of characteristics, we will explore extending the components framework to apply it to participant characteristics – this allows combinations of these to be modelled as having additive, synergistic or antagonistic impacts on effectiveness.

Social exclusion is associated with the poorest health outcomes (42) thus where there are sufficient data we will also examine the effectiveness of interventions to increase vaccine uptake in specific groups of the most underserved communities such as vulnerable migrants, Gypsy, Roma or Traveller communities and the homeless.

Identification of key gaps in the evidence

We will formally identify gaps in the evidence that could widen inequalities by tabulating the evidence for intervention effectiveness in different populations against key PROGRESS items (e.g. sex, ethnicity, socio-economic status, educational status) and for specific underserved communities (e.g. vulnerable migrants). We will work with our stakeholders and PPI group to determine which of the identified gaps in the evidence are most important and could potentially lead to a widening of inequalities. We will then aim to fill any such gaps, for example, by seeking information on 'what works' from existing best practice examples from trusted sources such NHS evidence insights 'Reducing health inequalities in vaccination' (43) and Royal College of General Practitioners rapid evidence reviews 'Increasing COVID-19 vaccination rates among vulnerable patients' (44). Then, where crucial gaps remain, we will seek input from our stakeholders and PPI group regarding their knowledge and views of which interventions (or components of interventions) they have observed working well, or believe could work well, in their population. Of note, these sources of information will not provide evidence of the same rigour as our core evidence synthesis. Appropriate caveats will therefore be applied to any such data used.

Patient and Public Involvement

We will recruit a PPI group of 8-10 people and identify three members to join the core project team (including a member from an underserved group). We will use a collaborative approach to work with our PPI contributors aligned to the INVOLVE definition 'an ongoing relationship between researchers and the members of the public…where the decisions about the research are shared' (45). Since there are known inequalities in vaccination according to factors such as ethnic group and deprivation, we aim to recruit a diverse group. This will be achieved by drawing on our links with People in Health West of England (PHWE), the NIHR Health Protection Research Unit in Behavioural Science and Evaluation community involvement projects, and the Health and Wellbeing Alliance, as needed.

With reference to the UK Standards for Public Involvement 'Inclusive opportunities' (46) we will strive to offer PPI opportunities that are accessible. We will use resources such as Equality Impact Assessments to ensure we are not inadvertently creating barriers to involvement. To ensure any issues identified are addressed, we will generate actions that are Smart, Measurable, Achievable, Realistic and Time-orientated. We will state who will take action, when, and how this will be monitored. Our Equality Impact Assessment will be a live document, reviewed prior to each PPI activity.

We will develop a communication plan with our PPI group to ensure our methods are flexible and inclusive. We will meet with PPI members regularly, initially to collaboratively shape a strategic approach to their role. Training on study methods will be provided during meetings, using materials

previously successfully used by the project team. The group will be asked to input into the research including: framing the research; refining the logic model and intervention coding; contextualising initial findings and shaping subsequent analyses; interpretation of findings and development of recommendations; and dissemination.

Our PPI lead will ensure that members are trained and supported in their role. We will identify the most appropriate tools (using PHWE's extensive resources) for our members and where required, will tailor these to their specific needs. Training and support to enable all members to join any online meetings will be provided as required.

We will incorporate PPI evaluation, using the Cube framework (47) and theory-driven logic models to evaluate impact. Our PPI lead will support PPI contributors to be involved in the evaluation processes.

References

1. Greenwood B. The contribution of vaccination to global health: past, present and future. *Philos Trans R Soc Lond B Biol Sci*. 2014;369(1645):20130433.
2. Fine P, Eames K, Heymann DL. "Herd immunity": a rough guide. *Clin Infect Dis*. 2011;52(7):911-6.
3. Iacobucci G. Child vaccination rates in England fall across the board, figures show. *BMJ*. 2019;366:l5773.
4. Pubic Health England. Quarterly vaccination coverage statistics for children aged up to 5 years in the UK (COVER programme): October to December 2021. 2022.
5. Mahase E. Measles cases rise 300% globally in first few months of 2019. *BMJ*. 2019;365:l1810.
6. Public Health England. PHE Infectious Diseases Strategy 2020-2025. 2019.
7. World Health Organization. Ten threats to global health in 2019. 2019 [Available from: https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019.
8. All-Party Parlimentary Group on Vaccinations for All. Improving vaccine uptake. 2021.
9. MacDonald NE, Sage Working Group on Vaccine Hesitancy. Vaccine hesitancy: Definition, scope and determinants. *Vaccine*. 2015;33(34):4161-4.
10. Jacobson Vann JC, Jacobson RM, Coyne-Beasley T, Asafu-Adjei JK, Szilagyi PG. Patient reminder and recall interventions to improve immunization rates. *Cochrane Database Syst Rev*. 2018;1:CD003941.
11. Thomas RE, Lorenzetti DL. Interventions to increase influenza vaccination rates of those 60 years and older in the community. *Cochrane Database Syst Rev*. 2018;5:CD005188.
12. Razai MS, Osama T, McKechnie DGJ, Majeed A. Covid-19 vaccine hesitancy among ethnic minority groups. *BMJ*. 2021;372:n513.
13. Public Health England. PHE Immunisation Inequalities Strategy. 2021.
14. Bocquier A, Ward J, Raude J, Peretti-Watel P, Verger P. Socioeconomic differences in childhood vaccination in developed countries: a systematic review of quantitative studies. *Expert Rev Vaccines*. 2017;16(11):1107-18.
15. National Institute for Health and Care Excellence. Vaccine uptake in the general population. NICE guideline [NG218] - Evidence reviews 2022.
16. Abbott R, Bethel A, Rogers M, Whear R, Orr N, Shaw L, et al. Characteristics, quality and volume of the first 5 months of the COVID-19 evidence synthesis infodemic: a meta-research study. *BMJ Evid Based Med*. 2021.
17. Ndze VN, Jaca A, Wiysonge CS. Reporting quality of systematic reviews of interventions aimed at improving vaccination coverage: compliance with PRISMA guidelines. *Hum Vaccin Immunother*. 2019;15(12):2836-43.
18. Anderson LJ, Shekelle P, Keeler E, Uscher-Pines L, Shanman R, Morton S, et al. The Cost of Interventions to Increase Influenza Vaccination: A Systematic Review. *Am J Prev Med*. 2018;54(2):299-315.
19. Ozawa S, Yemeke TT, Thompson KM. Systematic review of the incremental costs of interventions that increase immunization coverage. *Vaccine*. 2018;36(25):3641-9.
20. Hong K, Leidner AJ, Tsai Y, Tang Z, Cho BH, Stokley S. Costs of Interventions to Increase Vaccination Coverage Among Children in the United States: A Systematic Review. *Acad Pediatr*. 2021;21(4S):S67-S77.
21. Munk C, Portnoy A, Suharlim C, Clarke-Deelder E, Brenzel L, Resch SC, et al. Systematic review of the costs and effectiveness of interventions to increase infant vaccination coverage in low- and middle-income countries. *BMC Health Serv Res*. 2019;19(1):741.
22. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors). *Cochrane Handbook for Systematic Reviews of Interventions* version 6.3 (updated February 2022). Cochrane, 2022. Available from: https://www.training.cochrane.org/handbook
23. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.

24. Centers for Disease Control and Prevention. The community guide - Increasing appropriate vaccination factsheet. 2021. Available from: https://www.thecommunityguide.org/resources/what-works-increasing-appropriate-vaccination [Accessed 14 September 2022].
25. National Institute for Health and Care Excellence. Flu vaccination: increasing uptake NICE guideline [NG103] - Evidence reviews. 2018.
26. Sterne JAC, Savovic J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:l4898.
27. Nikolakopoulou A, Higgins JPT, Papakonstantinou T, Chaimani A, Del Giovane C, Egger M, et al. CINeMA: An approach for assessing confidence in the results of a network meta-analysis. *PLoS Med*. 2020;17(4):e1003082.
28. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol*. 2011;64(4):383-94.
29. Drummond MF, Sculpher MJ, Claxton K, Stoddart GL, Torrance GW. Methods for the Economic Evaluation of Health Care Programmes. 4th ed. Oxford: Oxford University Press; 2015.
30. Larson HJ, Jarrett C, Eckersberger E, Smith DM, Paterson P. Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: a systematic review of published literature, 2007-2012. *Vaccine*. 2014;32(19):2150-9.
31. Thomson A, Robinson K, Vallee-Tourangeau G. The 5As: A practical taxonomy for the determinants of vaccine uptake. *Vaccine*. 2016;34(8):1018-24.
32. Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, et al. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med*. 2013;46(1):81-95.
33. Rogers RW. A Protection Motivation Theory of Fear Appeals and Attitude Change1. *J Psychol*. 1975;91(1):93-114.
34. Horne R, Chapman SC, Parham R, Freemantle N, Forbes A, Cooper V. Understanding patients' adherence-related beliefs about medicines prescribed for long-term conditions: a meta-analytic review of the Necessity-Concerns Framework. *PLoS One*. 2013;8(12):e80633.
35. O'Brien N, Heaven B, Teal G, Evans EH, Cleland C, Moffatt S, et al. Integrating Evidence From Systematic Reviews, Qualitative Research, and Expert Knowledge Using Co-Design Techniques to Develop a Web-Based Intervention for People in the Retirement Transition. *J Med Internet Res*. 2016;18(8):e210.
36. Santillo M, Sivyer K, Krusche A, Mowbray F, Jones N, Peto TEA, et al. Intervention planning for Antibiotic Review Kit (ARK): a digital and behavioural intervention to safely review and reduce antibiotic prescriptions in acute and general medicine. *J Antimicrob Chemother*. 2019;74(11):3362-70.
37. Dias S, Welton NJ, Caldwell DM, Ades AE. Checking consistency in mixed treatment comparison meta-analysis. *Stat Med*. 2010;29(7-8):932-44.
38. Higgins JP, Jackson D, Barrett JK, Lu G, Ades AE, White IR. Consistency and inconsistency in network meta-analysis: concepts and models for multi-arm studies. *Res Synth Methods*. 2012;3(2):98-110.
39. Salanti G. Indirect and mixed-treatment comparison, network, or multiple-treatments meta-analysis: many names, many benefits, many concerns for the next generation evidence synthesis tool. *Res Synth Methods*. 2012;3(2):80-97.
40. Craig P, Di Ruggiero E, Frohlich KL, Mykhalovskiy E, White M, on behalf of the Canadian Institutes of Health Research (CIHR)–National Institute for Health Research (NIHR) Context Guidance Authors Group. Taking account of context in population health intervention research: guidance for producers, users and funders of research. Southampton: NIHR Evaluation, Trials and Studies Coordinating Centre; 2018.
41. O'Neill J, Tabish H, Welch V, Petticrew M, Pottie K, Clarke M, et al. Applying an equity lens to interventions: using PROGRESS ensures consideration of socially stratifying factors to illuminate inequities in health. *J Clin Epidemiol*. 2014;67(1):56-64.
42. Marmot M. Inclusion health: addressing the causes of the causes. *Lancet*. 2018;391(10117):186-8.

43. NHS England and NHS Improvement coronavirus. Reducing health inequalities in vaccine uptake. 2021. Available from: https://www.england.nhs.uk/coronavirus/reducing-health-inequalities-in-vaccine-uptake/ [Accessed 14 September 2022].
44. Royal College of General Practitioners. Increasing uptake of vaccinations for vulnerable groups of patients: Evidence reviews. 2021. Available from: https://elearning.rcgp.org.uk/mod/page/view.php?id=11930 [Accessed 14 September 2022].
45. National Institute for Health and Care Excellence. Briefing notes for researchers - public involvement in NHS, health and social care research. 2021. Available from: https://www.nihr.ac.uk/documents/briefing-notes-for-researchers-public-involvement-in-nhs-health-and-social-care-research/27371 [Accessed 14 September 2022].
46. National Institute for Health and Care Excellence. UK Standards for Public Involvement- Better public involvement for better health and social care research. 2019.
47. Gibson A, Welsman J, Britten N. Evaluating patient and public involvement in health research: from theoretical model to practical workshop. *Health Expect*. 2017;20(5):826-35.