Lessons for COVID-19 Vaccination from Eight Federal Government Direct Communication Evaluations

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Summary

The world is embarking on an unprecedented vaccination effort to combat the COVID-19 pandemic. We discuss eight randomized evaluations intended to increase vaccination uptake conducted by the United States General Services Administration's Office of Evaluation Sciences (OES). These evaluations had a median sample size of 55,000, deployed a variety of light-touch behaviorally-informed direct communications, and used administrative data to measure actual vaccination uptake. The confidence interval from an internal meta-analysis shows changes in vaccination rates ranging from -0.004 to 0.394 percentage points. Two of eight studies yielded statistically significant increases, of 0.59 and 0.16 percentage points. The other six results were not statistically significant, although the studies were powered to detect effect sizes in line with past published research. This work highlights the likely effects of government communications and demonstrates the value of conducting rapid evaluations to enable evidence building and support COVID-19 vaccination efforts.

Keywords: vaccination, randomized controlled trial, communications, government evaluation

The world is embarking on an unprecedented vaccination effort to combat the COVID-19 pandemic and governments are developing recommendations for getting the vaccine to as many people as possible.[1] However, vaccination rates for many vaccines fall well below recommendations, both in the United States[2,3] and in other countries.[4,5] Direct communications to individual citizens are a critical touchpoint by which governments can encourage the public to vaccinate; for instance, one of the five goals in the U.S. National Vaccine Plan is to "support communications to enhance informed vaccine decision-making." But evidence of how large a difference government communications can make on vaccination rates is limited.

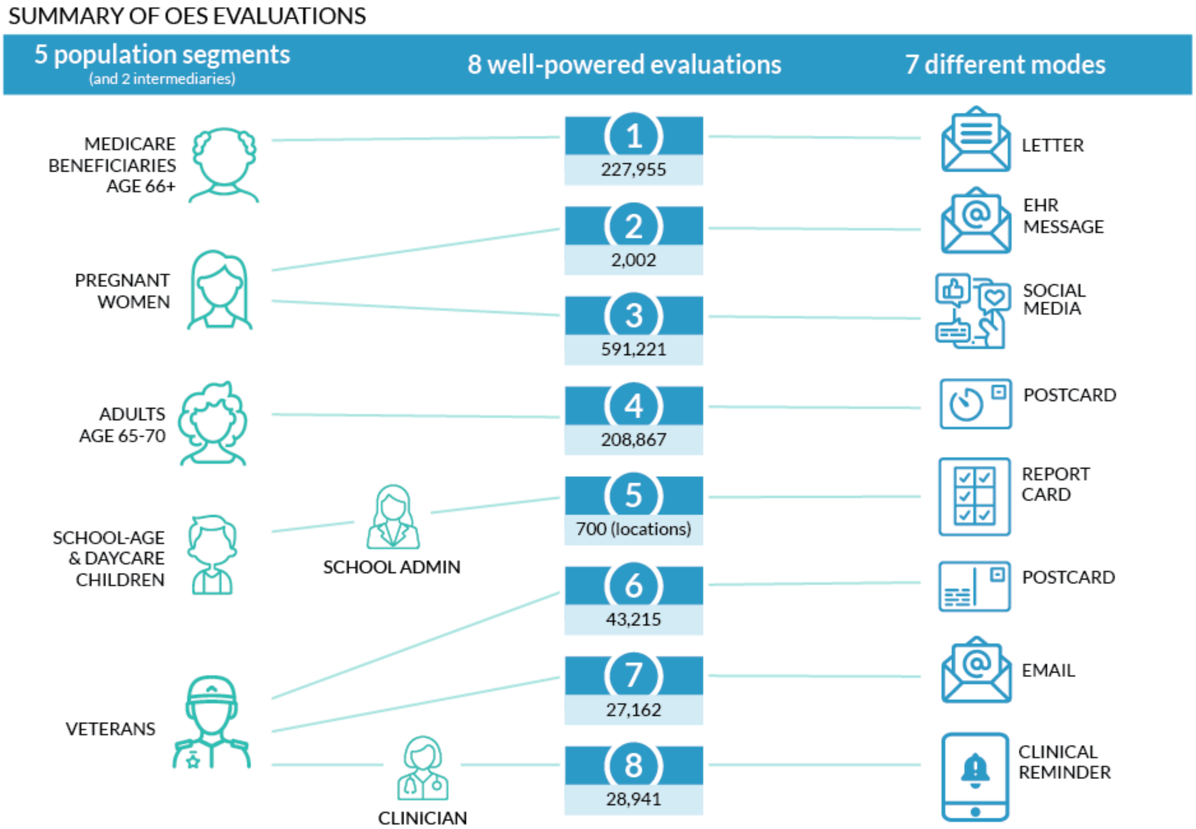
Communications have the potential to address a number of behavioral barriers that might prevent a person from vaccinating. A person may, for example, be unaware that a vaccine is available and recommended for them; not believe that the vaccination is safe or effective; not form an intention to get vaccinated; or not remember or be able to act on an intention to vaccinate. Research from behavioral science provides insights on how to design direct communications like letters or emails to overcome such behavioral barriers.[6-8] However, there has been limited opportunity to evaluate these communications interventions in the context of large-scale, real-world behavior.

The United States General Services Administration's Office of Evaluation Sciences (OES) is a team of interdisciplinary experts that works across the US government to help agencies build and use evidence, including by applying behavioral insights. OES had the opportunity from 2015 to 2019 to conduct eight randomized evaluations drawing on behavioral insights in which the office designed and tested direct communication about vaccination uptake at scale ("the OES vaccination portfolio"). OES conducted the evaluations in collaboration with a private health facility, a city department of health, a state department of health, three Veterans

Health Affairs health care systems, and one operating division in the US Department of Health and Human Services. These evaluations had a median sample size of 55,000 recipients and used existing administrative data to measure actual vaccination uptake. Participants were drawn from populations where there were strong vaccination recommendations (e.g., young children; pregnant women; older adults) and several of the samples had high proportions of historically underrepresented groups (e.g, the Atlanta Veterans Affairs sample was > 50% Black). The interventions ranged from email, postcard, letter, or social media notifications for potential vaccine recipients to a more formal report card of a school's vaccination compliance rate for school administrators or intensive change to a hospital's electronic health record (EHR) clinical reminders for clinicians. The behavioral insights utilized in the interventions were also varied, including reminders, planning prompts, social norms messaging, persuasive appeals, and message source and timing variations.

Although the outcomes in the OES evaluations pertained to receiving routine vaccinations such as influenza (see Table 1), the lessons learned are also important for the worldwide COVID-19 vaccination program, where we will likely witness slow-downs in vaccination rates after initial surges of demand are met. Also relevant to the COVID-19 pandemic, many of these randomized evaluations were implemented within active and ongoing vaccination efforts (e.g., the VA administers vaccines to veterans; city and state departments of health are involved in tracking and encouraging vaccinations among their residents), highlighting the feasibility of running large-scale evaluations to learn what works in real time.

Figure 1. Overview of OES vaccination uptake evaluations, showing the population segments that were sampled, the sample sizes, and the modes of communication



Note. Evaluation details are in Table 1.

Every evaluation encouraging vaccination uptake that OES conducted in the 2015-2019 time-frame is reported here (see Table 1), and thus the interpretation of effects is not subject to publication bias.[9] The minimum detectable effect (MDE) was as small as .04pp (Evaluation 1), and all but one evaluation had an MDE smaller than 1.7pp, an effect size that is at the smaller end of previous published literature (two salient and similar studies reported effects in the 2 to 4pp range[10,11]). These two features are especially important in light of a recent analysis suggesting that the combination of publication bias and low statistical power in academic journal articles can account for the 7.3 percentage point increase in average effects of "nudge" interventions published in these journals, compared to those conducted by government units.[12] The OES vaccination portfolio represents a unique set of eight well-powered evaluations conducted in a U.S. government context, showing the change in vaccination uptake that has been achieved when behaviorally-informed direct communications about vaccination are provided by government agencies.

Table 1. Details of OES vaccination uptake evaluations, showing key project characteristics including primary collaborator, project context, evaluation design, and key findings

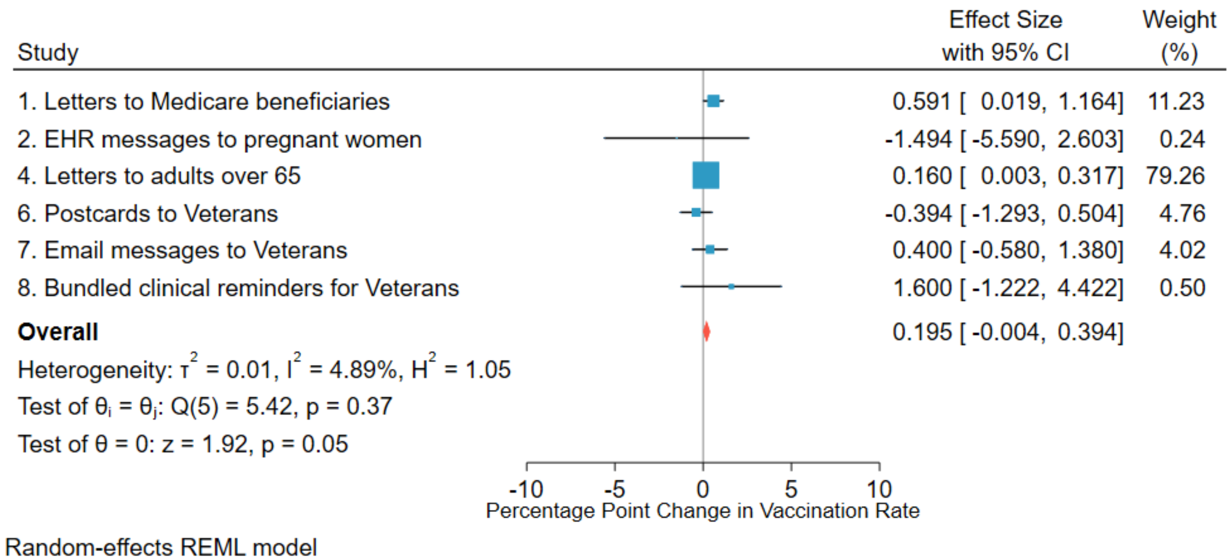
#	Collaborator	Sample Size	Vaccine Type	Population	Year(s)	Outcome	Treatment Group	Comparison Group	Treat Mean	Ctrl Mean	Key Findings	Cost
1	Centers for Medicare and Medicaid Services	227,955	Influenza	Medicare beneficiaries 66+	2014-15	Vaccination uptake	One of four letters encouraging flu vaccination	No Letter	26.5% (avg. across treatments)	25.9%	Any letter compared to no letter statistically significantly increased vaccination rates by 0.59 percentage points. A letter from the Surgeon General generated the largest effects.	Low
2	Duke University Health System	2,002	Influenza	Pregnant women	2016-17	Vaccination uptake	Targeted EHR message on the flu vaccine	No targeted EHR message	38.3%	40.1%	The targeted message generated a statistically insignificant (1.5 percentage point) drop in flu vaccine uptake.	Very low
3	National Vaccine Program Office	591,221	Influenza, Whooping cough	Potentially pregnant women	2017	Ad click rates	One of four variations of ads highlighting maternal immunization	Ad variations (no one comparison group)	0.15-0.16% (across treatments)	NA	The ads had no differential impact on click-through rates.	No cost
4	Louisiana Department of Health	208,867	Numerous	Adults (65-70) overdue for at least one of four vaccines	2017-18	Vaccination uptake	A postcard reminder sent in October, November, or December.	January postcard	8.75%* (avg. across treatments)	8.59%	The October reminder had a small but statistically significant effect (0.3 percentage points), while postcards sent later had no effect.	No cost
5	City Department of Health	700 schools	All required childhood vaccines	School and daycare center leadership	2017-18	Vaccine compliance	A vaccine compliance report card.	No report card	76.3%	76.2%	The report card did not increase immunization compliance at treated schools compared to control schools.	Moderate
6	St Cloud Veterans Affairs	43,215	Influenza	Veterans 18+	2017-18	Vaccination uptake	One of two postcards informed by insights from the behavioral sciences	Basic (not behaviorally-informed) postcard	40.0%	40.1%	The postcards informed by insights from the behavioral sciences generated a combined statistically insignificant (0.4 percentage points) drop in vaccine uptake.	No cost
7	New York Harbor Veterans Affairs	27,162	Influenza	Veterans 18+	2017-18	Vaccination uptake	Email encouraging flu vaccination and providing action-relevant information	No email	20.3%	20.2%	The email message generated a statistically insignificant increase (0.4 percentage points) in vaccination uptake and also did not affect vaccination timing.	Very low
8	Atlanta Veterans Affairs	28,941	Influenza, Pneumococcal, Tdap	Veterans 18+	2018-19	Vaccination uptake, all appts in study period	Primary care teams received modified clinical reminders in the EHR system, vaccination dashboard, and suggested talking points	Status quo EHR system	20.74%	19.18%	The EHR intervention generated a statistically insignificant increase (1.6 percentage points) in vaccination rates among treated patients.	Multiple / unknown

Note. Cost estimates refer to the ongoing marginal cost to deliver an intervention, based on assumptions about the relative cost of these various distribution types. This costing framework is discussed in more detail in reference[22]. Treatment means are calculated based on the raw data unless indicated by *, in which case the mean is calculated based on regression coefficients due to data availability constraints. For further information about these evaluations, please see the references: Evaluation 1,[13, 37] Evaluation 2,[38] Evaluation 3,[39] Evaluation 4,[14,40] Evaluation 5,[41,42] Evaluation 6,[43] Evaluation 7,[44], Evaluation 8.[45]

Two of the eight individual evaluations yielded statistically significant effects. Letter reminders about influenza vaccination sent to Medicare beneficiaries ages 66 and over increased the probability of influenza vaccination by 0.4 to 0.7 percentage points (relative to a group who received no reminder letter), although there was no difference between five different letter versions.[13] Postcard reminders sent in October 2017 to Louisiana residents aged 65-70 increased the proportion of influenza, tetanus, pneumococcal, and shingles vaccinations they received by 0.27 percentage points, although postcards mailed in November and December did not have a detectable effect.[14]

This set of studies meets the criteria for producing a valid internal meta-analysis.[15] OES provides detailed pre-analysis plans for all evaluations, and commits to sharing the results of all evaluations; it has no "file drawer." An internal meta-analysis of the six evaluations that measured vaccination rates at the individual level (Figure 2) showed an overall effect size that is positive but small and with a confidence interval that includes the null: 0.19 percentage points [95% CI -0.004, 0.394]. This suggests that interventions like those in the OES evaluations are unlikely to reliably generate effects of more than about half a percentage point.

Figure 2. Internal meta-analysis of six OES evaluations with vaccination uptake as the common outcome



Note. This figure shows coefficients from studies included in an internal meta-analysis of OES vaccination evaluations targeted at the individual client level. Evaluation numbers correspond to descriptions in Table 1. The meta-analysis relies on a random-effects maximum likelihood model, using inverse variance weighting. The blue squares reflect the average effect of the treatment in each evaluation on the percentage point change in the relevant vaccination rate, where the size of the squares depend on the weight attributed to that evaluation. 95% confidence intervals based on the standard errors from the relevant regression are shown in black. The red diamond represents the overall effect across studies, as estimated by the meta-analysis. Finally, the meta-analysis reports τ^2, or an estimator of the between-evaluation variance; I^2, or the proportion of total variation in the estimates of the treatment effects that is due to heterogeneity between studies; and H^2, or a measure of the impact of heterogeneity.

Two of the OES evaluations are not included in the internal meta-analysis because they had different outcomes: one aimed to increase click rates on an ad encouraging vaccination uptake and the other to increase school immunization compliance by sharing compliance report cards with school administrators (Evaluations 3 and 5 in Table 1). Neither of those evaluations observed a statistically significant effect for the intervention they employed.

There are four key lessons for future vaccination efforts, including the COVID-19 vaccination program. We start by sharing two takeaways from the results of the evaluations, before moving to two takeaways from the process of conducting the evaluations.

1. Behaviorally-informed direct communications can increase vaccination rates at scale but may have smaller, less reliable effects than the published literature suggests.

The OES evaluations provide a ballpark for the effects we might expect of behaviorally-informed direct communications at scale. For the six evaluations that directly measured vaccination at the individual level, the meta-analytic effect was small [95% CI: -0.004, 0.394]. Two out of eight evaluations, which both used mailed reminders, yielded statistically significant effects. Although small, these effects did result in thousands of additional vaccinations, which may still be considered meaningful by program managers.

These results are important because a review of published studies on these types of interventions may (mis)lead those planning a COVID-19 vaccination campaign to overestimate their effects. To date, relatively few tests of behaviorally-informed direct communications have observed actual vaccination rates as an outcome. In two studies that did observe actual vaccination, albeit with sample sizes under 10,000 participants, effects were in the 2 to 4pp range.[10,11] A systematic review of email reminders about vaccination found increases ranging from two to eleven percentage points for people sent an email compared to no reminder.[16]

The OES evaluations differ from the wider literature as well as from the original published studies that motivated the scaled-up interventions in a variety of ways that might allow for a more realistic estimate of the effects at scale. First, six of the eight OES evaluations measured actual vaccination uptake. Much of the literature applying behavioral science to vaccination focuses on thoughts and feelings about vaccinations rather than actual vaccination uptake.[6] It is common for published studies to measure the likelihood of vaccination in a hypothetical scenario,[e.g.,17] or the intention to be vaccinated rather than actual vaccination uptake, but people often fail to follow through on their intentions to act.[18] Second, the median sample size across the eight OES evaluations was 55,000 recipients, which is considerably larger than that reported in most published studies. Third, OES reported on the results of every evaluation it conducted. Publication bias in academic journals, combined with lower-powered studies, might lead the published literature to report larger effect sizes than those observed in subsequent scaled-up efforts.[12]

Fourth, the success of vaccination uptake interventions may depend on the context in ways that systematic coordinated evaluations can highlight. One recent field experiment tested 19 different text messages in a sample of roughly 47,000 patients with an upcoming primary care appointment, and found an average increase of 2.1 percentage points in vaccination uptake.[19] However, that experiment sent text messages from primary care providers to a sample of patients who had upcoming appointments. The difference between that context and the government sending letters to older adults on Medicare (for instance) may contribute to the smaller effects observed in the OES evaluations. Fifth, and building on the previous point, the target audience may be differently responsive to messaging. And finally, working at large scale and in a government context sometimes affects which elements of a messaging campaign can be included. We discuss this point in more detail in our third takeaway.

The finding that behaviorally-informed direct communications are likely to have only small effects at scale highlights the importance of sample size when considering the value of running a randomized controlled trial to evaluate the efficacy of such interventions. In many cases, the sample for an RCT needs to be quite large (several thousands of people) to achieve sufficient power to detect effects.

2. Additional evidence is needed to evaluate the cost effectiveness of behaviorally-informed direct communications relative to other interventions.

Arguments in favor of small interventions tend to emphasize that these are cheap to implement per recipient. “Light-touch” approaches like direct communications are generally seen as low-cost per participant and easy to implement relative to heavier-handed approaches like redesigning forms, pre-scheduling appointments, or offering material incentives. Also, direct communications can more precisely target particular individuals or sub-groups than is possible with extensive commercial advertising campaigns.

Only a few researchers have examined the cost effectiveness of behavioral science interventions as compared to alternative approaches such as financial incentives or policy mandates.[20-22] These papers generally find that behavioral interventions compare favorably to other approaches. A published report of one of the OES vaccination uptake evaluations[13] extrapolated from the cost of printing and sending letters to argue that the cost per additional vaccination, in the most effective treatment arm, was approximately $90, in line with costs of other approaches. But there is, as yet, very little systematic comparison of cost-effectiveness for vaccination uptake interventions. The small effect sizes in the OES evaluations highlight the value of cost information to make informed comparisons.

To date, OES vaccination uptake evaluations have not collected comprehensive cost information including hours and salary costs for those involved in delivering an intervention, since this type of information has proven difficult and time-consuming to collect. In part, this was the case because such collection would have required sharing budgetary data across separate government entities; this implies that in future studies that are performed within one institution, cost estimates may be easier to perform. However, OES recently developed a framework to roughly categorize interventions based on the approximate ongoing marginal cost to deliver the intervention.[23] Using this framework, the eight vaccination uptake interventions include three with no cost (no new change to delivery medium), two at very low cost (added an email), one at low cost (added printing and mailing), one at moderate cost (added staffing costs as part of intervention delivery), and one with multiple/unknown costs (redesigned the electronic health record messaging). The small effect sizes observed for behaviorally-informed direct communications suggest that it may be most sensible to deploy these interventions when it can be done at no or very low cost, such as by editing an existing communication pipeline.

To build stronger evidence about cost-effectiveness, more comprehensive cost data needs to be recorded in future research.[24] Ideally researchers would go beyond printing and mailing costs, capturing both administrative costs to design and deliver such interventions and the burdens such interventions incur for recipients.[25,26] For example, one possible comparison is between behaviorally-informed direct communications and material incentives.[27] Several studies have found that monetary payments increased vaccination rates.[28,29] If payments have orders-of-magnitude larger effects on vaccination, they may actually be a more cost-effective strategy than lower-cost (per target) direct communications. Additionally, if these strategies change the behavior of non-identical groups of people, it may be cost-effective to use both approaches in parallel.

Whereas the lessons above pertain to the results of the evaluations—to the effect of each intervention on vaccination uptake—there are also two lessons learned from the process of conducting those evaluations.

3**. Rapid evaluations of vaccination uptake interventions in real-world contexts are essential for learning what works in specific contexts for populations of interest.**

The OES vaccination portfolio testifies to the importance of evaluating interventions as they are deployed in the field. Both implementation details and effect sizes appear to be highly context dependent, so testing directly in the context of application is key. As more people are included, the statistical power to detect meaningful effects is also improved. Learning can be greatly enhanced if vaccination campaigns incorporate rapid evaluations of different approaches, rather than deploying a system-wide rollout of one strategy. Widespread and rapid randomized controlled trials of vaccination uptake interventions could enable the COVID-19 vaccination campaign to build evidence about how much (if at all) interventions work to increase vaccination rates.

An important contribution of the OES vaccination portfolio is to demonstrate that, when scaling up best practices in the literature, practical constraints may "dilute" the original treatment effect. For example, OES drew on a study that had added a planning prompt to a letter listing the days, times, and location of a workplace vaccination clinic sent to about 3,200 utility company employees.[11] OES added planning prompts to some of the letters sent to 228,000 Medicare beneficiaries (Evaluation 1 in Table 1),[13] but it was not feasible to include information about locations and opening hours of local vaccination clinics. Results of the OES evaluation, which showed a smaller increase in vaccination uptake than the original research, suggest that the location and opening hours may be a necessary component to reap the full benefit of the planning prompt. Before attempting the evaluation at scale, it was not obvious that locations and opening hours could not be feasibly added to beneficiary letters, nor was it known how much the changes would reduce effectiveness. These sorts of limitations may only be evident when evaluating in the target context.

A second example of practical constraints comes from a modified clinical reminder built into an electronic health records system at the Atlanta Veterans Affairs Medical Center (Evaluation 8 in Table 1). Dempsey and colleagues[30] tested an intervention that included training providers for two-and-a-half hours in how to use presumptive language for HPV vaccinations, and found a 9.5pp increase in human papilloma virus vaccine series initiation (see also [31] with a 1-hour training). In the OES evaluation at the Atlanta VA, we attempted to replicate this approach, but for practical reasons could not deliver an hours-long training. Instead, we modified the electronic health records system to encourage providers to use language that presumed the patient would vaccinate (e.g., “It is time for your X shot today”). Simply including linguistic prompts in electronic health records system messages is much lighter-touch. However, conversations with providers in the OES evaluation indicated that many did not actually use the presumptive language as suggested. This implementation information is invaluable for informing the design of future interventions, which can either try alternative light-touch approaches or employ more intensive training.

4. Leveraging vaccination administration systems to support randomized evaluations can make evidence building easier.

The OES vaccination portfolio demonstrates the value of working within vaccination administration systems that can support randomized evaluations.[32] These studies were conducted quickly (often within a single influenza season) and at low cost by making behaviorally-informed design changes to content or timing within existing communications programs, and delivering variants to randomly selected recipients using existing systems. OES projects show that randomized evaluation can be embedded in a variety of systems with differing data capabilities and even with complex administrative systems, ranging from a city department of health to a regional Veterans Affairs Health Center. A system need not be specially designed for RCTs to enable randomized evaluations. It would be particularly easy to do evaluations on a national scale if there were a single federal Immunization Information System (IIS), or if existing local IISs were standardized, to enable the identification and random assignment to interventions of potential vaccination recipients.

The OES evaluations measured outcomes at low cost by using existing administrative data, such as that captured by state immunization registries, electronic health records, and medical claims databases. The more comprehensive and up-to-date the databases, the more useful they are for measuring outcomes in evaluations. For instance, the availability of real-time data was crucial to the success of the OES collaboration with the city department of health because it facilitated the introduction of up-to-date immunization compliance report cards for schools. In contrast, the Louisiana Department of Health evaluation was complicated by the fact that health care providers are not required to report adult vaccinations.

These procedural lessons can inform evaluations of COVID-19 vaccination uptake interventions. If evaluations are built in at an early stage, then practitioners could quickly (and relatively cheaply) learn how to tweak their efforts based on observed results,[33,34] leading in turn to vaccination efforts that are increasingly effective over time.

Conclusion

The success of efforts to combat the COVID-19 pandemic will depend critically on whether people get vaccinated. Communications are a key tool that governments can use to encourage vaccination. Eight randomized evaluations show that direct communications may increase vaccination uptake, but the effect size from an internal meta-analysis is small (95% CI: -0.004, 0.394]. The small effects imply that these communications are a complement to—not a substitute for—vaccination policies and programmatic operations (e.g. the widespread availability of free vaccinations, perhaps with incentives or mandates) .

It is worth considering how the context of COVID-19 vaccinations may differ from the context for influenza and other routine vaccinations. Communications that increase the uptake of influenza and other common vaccines typically do so by reminding people who may otherwise forget and making it easier for them to follow through on existing intentions.[6] One review described this as " ...leveraging, but not trying to change, what people think and feel."[6] These interventions are typically deployed in situations where vaccine supply exceeds demand. The initial demand for COVID-19 vaccinations in the United States exceeded supply, and in the summer of 2021 this is still true in most parts of the world. However, as COVID-19 vaccines become more widely available in these areas, our takeaways will be particularly relevant. As vaccination efforts proceed, the OES evaluations highlight the importance of rapid evaluations of vaccination uptake interventions and demonstrate the possibilities of leveraging vaccination administration systems to support randomized evaluation. Planning for these evaluations now and deploying them soon will allow for much-needed evidence building about how to best apply communications and other interventions as part of current and future vaccination efforts.

References

1. United States Department of Health and Human Services. *COVID-19 vaccine distribution*. https://www.hhs.gov/coronavirus/covid-19-vaccines/distribution/index.html, last accessed December 21, 2020.

2. Approved by the National Vaccine Advisory Committee on September 17, 2019. (2020). 2020 National Vaccine Plan Development: Recommendations From the National Vaccine Advisory Committee. *Public Health Reports*, *135*(2), 181-188.

3. Norris, T., Vahratian, A., & Cohen, R. A. (2017). *Vaccination coverage among adults aged 65 and over: United States, 2015*. US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics.

4. Tacken, M. A., Jansen, B., Mulder, J., Campbell, S. M., & Braspenning, J. C. (2015). Dutch influenza vaccination rate drops for fifth consecutive year. *Vaccine*, *33*(38), 4886-4891.

5. Iacobucci, G. (2019). Child vaccination rates in England fall across the board, figures show. *BMJ*, *366*.

6. Brewer, N. T., Chapman, G. B., Rothman, A. J., Leask, J., & Kempe, A. (2017). Increasing vaccination: putting psychological science into action. *Psychological Science in the Public Interest*, *18*(3), 149-207.

7. Chen, F., & Stevens, R. (2017). Applying lessons from behavioral economics to increase flu vaccination rates. *Health promotion international*, *32*(6), 1067-1073.

8. Chou, W.-Y.S., Burgdorf, C.E., Gaysynsky, A., & Hunter, C.E. (2020). *COVID-19 vaccination communication: Applying behavioral and social science to address vaccine hesitancy and foster vaccine confidence.* National Institutes of Health. https://obssr.od.nih.gov/wp-content/uploads/2020/12/COVIDReport_Final.pdf, last accessed December 21, 2020.

9. Franco, A., Malhotra, N., & Simonovits, G. (2014). Publication bias in the social sciences: Unlocking the file drawer. *Science*, *345*(6203), 1502-1505.

10. Stockwell, M. S., Kharbanda, E. O., Martinez, R. A., Vargas, C. Y., Vawdrey, D. K., & Camargo, S. (2012). Effect of a text messaging intervention on influenza vaccination in an urban, low-income pediatric and adolescent population: a randomized controlled trial. *Jama*, *307*(16), 1702-1708.

11. Milkman, K. L., Beshears, J., Choi, J. J., Laibson, D., & Madrian, B. C. (2011). Using implementation intentions prompts to enhance influenza vaccination rates. *Proceedings of the National Academy of Sciences*, *108*(26), 10415-10420.

12. DellaVigna, S., & Linos, E. (2020). *Rcts to scale: Comprehensive evidence from two nudge units* (No. w27594). National Bureau of Economic Research.

13. Yokum, D., Lauffenburger, J. C., Ghazinouri, R., & Choudhry, N. K. (2018). Letters designed with behavioural science increase influenza vaccination in Medicare beneficiaries. *Nature human behaviour*, *2*(10), 743-749.

14. Chen, N., Trump, K. S., Hall, S., & Le, Q. The effect of postcard reminders on vaccinations among the elderly: a block-randomized experiment. *Behavioural Public Policy*, 1-26.

15. Vosgerau, J., Simonsohn, U., Nelson, L. D., & Simmons, J. P. (2019). 99% impossible: A valid, or falsifiable, internal meta-analysis. *Journal of Experimental Psychology: General*, *148*(9), 1628.

16. Frascella, B., Oradini-Alacreu, A., Balzarini, F., Signorelli, C., Lopalco, P. L., & Odone, A. (2020). Effectiveness of email-based reminders to increase vaccine uptake: a systematic review. *Vaccine*, *38*(3), 433-443.

17. Keller, P. A., Harlam, B., Loewenstein, G., & Volpp, K. G. (2011). Enhanced active choice: A new method to motivate behavior change. *Journal of Consumer psychology*, *21*(4), 376-383.

18. Sheeran, P., & Webb, T. L. (2016). The intention–behavior gap. *Social and personality psychology compass*, *10*(9), 503-518.

19. Milkman, K. L., Patel, M. S., Gandhi, L., Graci, H. N., Gromet, D. M., Ho, H., ... & Duckworth, A. L. (2021). A megastudy of text-based nudges encouraging patients to get vaccinated at an upcoming doctor's appointment. *Proceedings of the National Academy of Sciences*, *118*(20).

20. Benartzi, S., Beshears, J., Milkman, K. L., Sunstein, C. R., Thaler, R. H., Shankar, M., ... & Galing, S. (2017). Should governments invest more in nudging?. *Psychological science*, *28*(8), 1041-1055.

21. Patterson, R. W., & Skimmyhorn, W. L. (2021). How do behavioral approaches to increase savings compare? TIAA Institute Trends and Issues. Retrieved from https://origin-www.tiaainstitute.org/sites/default/files/presentations/2021-03/TIAA%20Institute_How%20do%20behavioral%20approaches%20to%20increase%20savings%20compare_TI_Skimmyhorn_March%202021.pdf

22. Wagner, Z., Montoy, J. C. C., Drabo, E. F., & Dow, W. H. (2020). Incentives versus defaults: Cost-effectiveness of behavioral approaches for HIV screening. *AIDS and Behavior*, *24*(2), 379-386.

23. Office of Evaluation Sciences. (2021). What does it cost to incorporate behaviorally informed interventions within government programs? https://oes.gsa.gov/blog/cost-analysis/

24. Dhaliwal, I., Duflo, E., Glennerster, R., & Tulloch, C. (2013). 8. Comparative Cost-Effectiveness Analysis to Inform Policy in Developing Countries: A General Framework

with Applications for Education. In *Education policy in developing countries* (pp. 285-338). University of Chicago Press.

25. Damgaard, M. T., & Gravert, C. (2018). The hidden costs of nudging: Experimental evidence from reminders in fundraising. *Journal of Public Economics*, *157*, 15-26.

26. Goldstein, D. G., Suri, S., McAfee, R. P., Ekstrand-Abueg, M., & Diaz, F. (2014). The economic and cognitive costs of annoying display advertisements. *Journal of Marketing Research*, *51*(6), 742-752.

27. Banerjee, A., Chandrasekhar, A. G., Dalpath, S., Duflo, E., Floretta, J., Jackson, M. O., ... & Shrestha, M. (2021). *Selecting the Most Effective Nudge: Evidence from a Large-Scale Experiment on Immunization* (No. w28726). National Bureau of Economic Research.

28. Bronchetti, E. T., Huffman, D. B., & Magenheim, E. (2015). Attention, intentions, and follow-through in preventive health behavior: Field experimental evidence on flu vaccination. *Journal of Economic Behavior & Organization*, *116*, 270-291.

29. Mantzari, E., Vogt, F., & Marteau, T. M. (2015). Financial incentives for increasing uptake of HPV vaccinations: a randomized controlled trial. *Health Psychology*, *34*(2), 160.

30. Dempsey, A. F., Pyrznawoski, J., Lockhart, S., Barnard, J., Campagna, E. J., Garrett, K., ... & O'Leary, S. T. (2018). Effect of a health care professional communication training intervention on adolescent human papillomavirus vaccination: a cluster randomized clinical trial. *JAMA pediatrics*, *172*(5), e180016-e180016.

31. Brewer, N. T., Hall, M. E., Malo, T. L., Gilkey, M. B., Quinn, B., & Lathren, C. (2017). Announcements versus conversations to improve HPV vaccination coverage: a randomized trial. *Pediatrics*, *139*(1).

32. Finkelstein, A. (2020). A strategy for improving US health care delivery—conducting more randomized, controlled trials. *New England Journal of Medicine*, *382*(16), 1485-1488.

33. Athey, S., Hadad, V., & Spiers, J. Considerations for adaptive pilot experiments. *Advances in Field Experiments* 2020 https://www.youtube.com/watch?v=hqTOPrUxDzM&list=PLTbpIpqWMIt8J3S4U4jDKZwBm8uiF614N&index=10, last accessed December 21, 2020.

34. Kasy, M., & Sautmann, A. (2021). Adaptive treatment assignment in experiments for policy choice. *Econometrica*, *89*(1), 113-132.

35. Loomba, S., de Figueiredo, A., Piatek, S., de Graaf, K., & Larson, H. J. (2020). Measuring the Impact of Exposure to COVID-19 Vaccine Misinformation on Vaccine Intent in the UK and US. *MedRXiv*.

36. Romer, D., & Jamieson, K. H. (2020). Conspiracy theories as barriers to controlling the spread of COVID-19 in the US. *Social science & medicine*, *263*, 113356.

37. Office of Evaluation Sciences. (2018). *Encouraging flu vaccine uptake among medicare beneficiaries*. https://oes.gsa.gov/assets/abstracts/15xx-medicare-flu-vaccine-uptake-abstract.pdf.

38. Office of Evaluation Sciences. (2018). *Increasing flu shot uptake among pregnant women*. https://oes.gsa.gov/assets/abstracts/1735-flu-shot-abstract.pdf.

39. Office of Evaluation Sciences. (2018). *Testing variations of maternal immunization messages*. https://oes.gsa.gov/assets/abstracts/1736-pregnancy-vaccines-ads-abstract.pdf.

40. Office of Evaluation Sciences. (2018). *Increasing vaccine uptake among seniors*. https://oes.gsa.gov/assets/abstracts/1738-increasing-vaccine-uptake.pdf.

41. Office of Evaluation Sciences. (2018). *Increasing immunization compliance in schools*. https://oes.gsa.gov/assets/abstracts/1737-vaccine-report-cards.pdf.

42. Leight, J., & Safran, E. (2019). Increasing immunization compliance among schools and day care centers: Evidence from a randomized controlled trial. *Journal of Behavioral Public Administration*, *2*(2).

43. Office of Evaluation Sciences. (2018). *Increasing flu shot uptake among St. Cloud Veterans*. https://oes.gsa.gov/assets/abstracts/1740-flu-shots-va-st-cloud.pdf.

44. Office of Evaluation Sciences. (2018). *Increasing flu shot uptake among New York Harbor Veterans*. https://oes.gsa.gov/assets/abstracts/1743-flu-shots-va-new-york-harbor.pdf.

45. Office of Evaluation Sciences. (2019). *Increasing vaccine uptake among Atlanta Veterans*. https://oes.gsa.gov/assets/abstracts/1803-vaccine-uptake-atlanta-va-abstract.pdf.

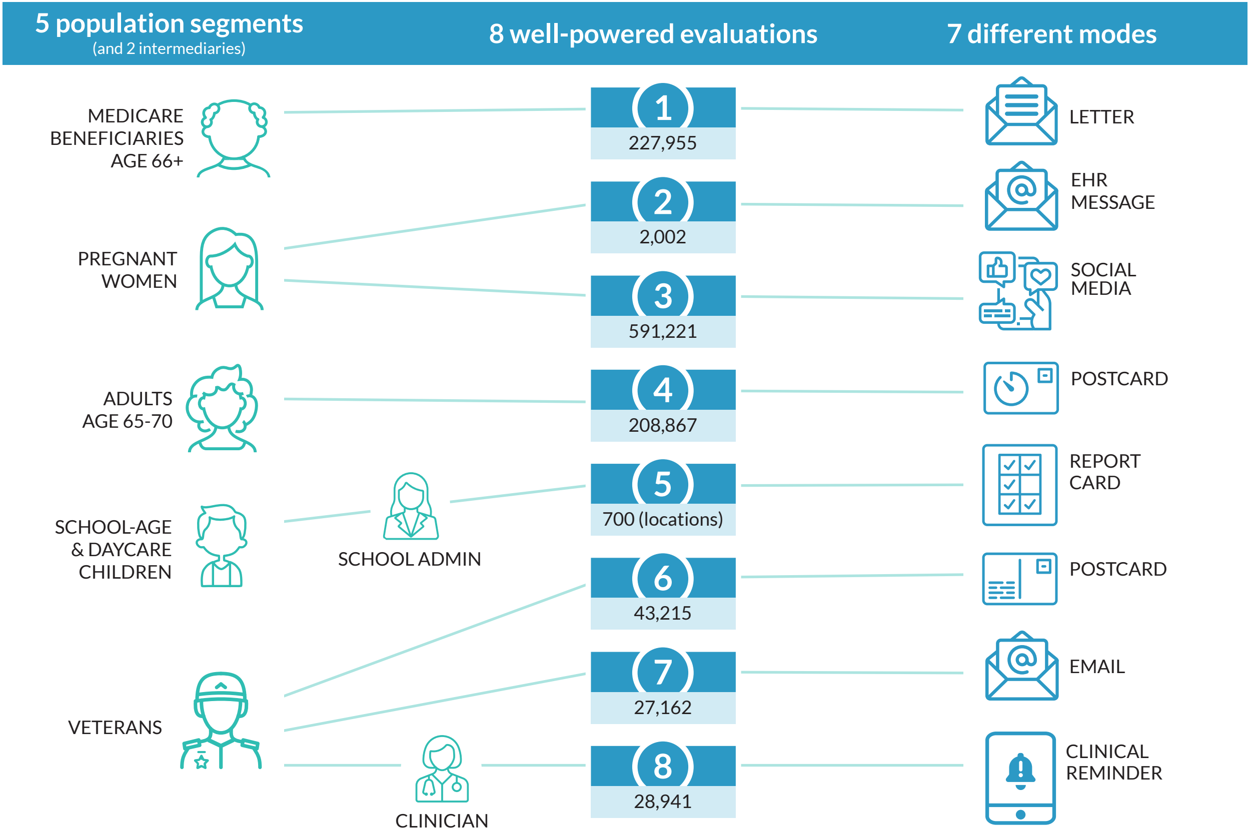
Acknowledgments

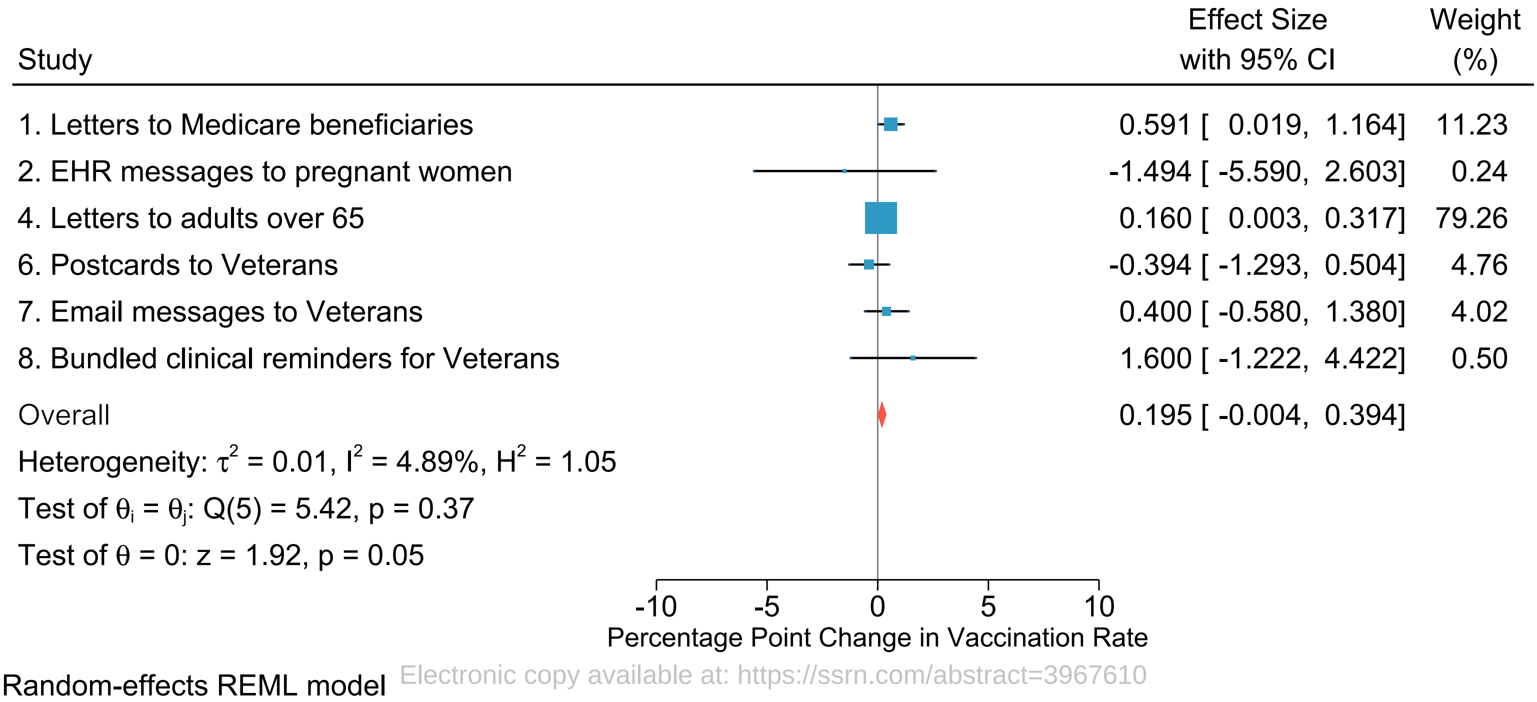
The authors would like to thank the many federal agencies, collaborators, academic affiliates, and the Office of Evaluation Sciences (OES) team members involved in developing and implementing the OES vaccination portfolio as well as the eight randomized evaluations referenced. We would like to acknowledge Bruce Gellin, Roula Sweis, Ann Aikin, Jordan Broderick, Judith Mendel, Kara Elam, Glen Nowak, Anju Abraham, Melinda Wharton and the US Department of Health and Human Services, the Office of Infectious Disease and HIV/AIDS Policy (formerly National Vaccine Program Office) for their time and guidance. Thank you to our collaborators in the U.S. Department of Veterans Affairs (VA) for their work and dedication, including Troy Knighton, Kathleen Pittman, Jane Kim and the National Center for Health Promotion and Disease Prevention team (NCP); Lois Katz, Craig Tenner and the VA New York Harbor Healthcare System staff; Judith Welter, Barry Venable, Dina Zwilling, Shawn Oglesby and the St. Cloud VA Health Care System staff; Vincent Marconi, Joseph Michael Wallace, Kelly Fripps, Florence Longchamp, Kathryn Meagley, and the Atlanta VA Medical Center staff. Thank you to the immunization program office at the city department of health and to Stacy Hall, Quan Le, Tony Fox, and the Louisiana Department of Health. Thank you to our collaborators at Duke University, including Kristin Weaver and Geeta Swamy. We would like to thank our collaborators at the Centers for Medicare and Medicaid Services (CMS) at the U.S. Department of Health and Human Services. This work was funded in part by NVPO and The Laura And John Arnold Foundation. We acknowledge the academic affiliates that contributed to this work and messaging, including David Bloom, Jessica Sullivan, the Harvard T.H. Chan School of Public Health, and the Value of Vaccination Research Network; Gretchen Chapman; Niteesh Choudhry, Roya Ghazinouri, Julie Lauffenburger and the Center for Healthcare Delivery Sciences at the

Brigham & Women's Hospital; Adam Berinsky; Eli Sprecher. Finally, thank you to the many team members at OES that assisted with and strengthened this work, including Kelly Bidwell, Amira Boland, Nicholas Wilson, Crystal Hall, Benjamin Kistler, Dennis Kramer, Jake Bowers, Jasper Cooper, Jessica Skretch, and countless others.

#	Collaborator	Sample Size	Vaccine Type	Population	Year(s)	Outcome	Treatment Group	Comparison Group	Treat Mean	Ctrl Mean	Key Findings	Cost
1	Centers for Medicare and Medicaid Services	227,955	Influenza	Medicare beneficiaries 66+	2014-15	Vaccination uptake	One of four letters encouraging flu vaccination	No Letter	26.5% (avg. across treatments)	25.9%	Any letter compared to no letter statistically significantly increased vaccination rates by 0.59 percentage points. A letter from the Surgeon General generated the largest effects.	Low
2	Duke University Health System	2,002	Influenza	Pregnant women	2016-17	Vaccination uptake	Targeted EHR message on the flu vaccine	No targeted EHR message	38.3%	40.1%	The targeted message generated a statistically insignificant (1.5 percentage point) drop in flu vaccine uptake.	Very low
3	National Vaccine Program Office	591,221	Influenza, Whooping cough	Potentially pregnant women	2017	Ad click rates	One of four variations of ads highlighting maternal immunization	Ad variations (no one comparison group)	0.15-0.16% (across treatments)	NA	The ads had no differential impact on click-through rates.	No cost
4	Louisiana Department of Health	208,867	Numerous	Adults (65-70) overdue for at least one of four vaccines	2017-18	Vaccination uptake	A postcard reminder sent in October, November, or December.	January postcard	8.75%* (avg. across treatments)	8.59%	The October reminder had a small but statistically significant effect (0.3 percentage points), while postcards sent later had no effect.	No cost
5	City Department of Health	700 schools	All required childhood vaccines	School and daycare center leadership	2017-18	Vaccine compliance	A vaccine compliance report card.	No report card	76.3%	76.2%	The report card did not increase immunization compliance at treated schools compared to control schools.	Moderate
6	St Cloud Veterans Affairs	43,215	Influenza	Veterans 18+	2017-18	Vaccination uptake	One of two postcards informed by insights from the behavioral sciences	Basic (not behaviorally-informed) postcard	40.0%	40.1%	The postcards informed by insights from the behavioral sciences generated a combined statistically insignificant (0.4 percentage points) drop in vaccine uptake.	No cost
7	New York Harbor Veterans Affairs	27,162	Influenza	Veterans 18+	2017-18	Vaccination uptake	Email encouraging flu vaccination and providing action-relevant information	No email	20.3%	20.2%	The email message generated a statistically insignificant increase (0.4 percentage points) in vaccination uptake and also did not affect vaccination timing.	Very low
8	Atlanta Veterans Affairs	28,941	Influenza, Pneumococcal, Tdap	Veterans 18+	2018-19	Vaccination uptake, all appts in study period	Primary care teams received modified clinical reminders in the EHR system, vaccination dashboard, and suggested talking points	Status quo EHR system	20.74%	19.18%	The EHR intervention generated a statistically insignificant increase (1.6 percentage points) in vaccination rates among treated patients.	Multiple / unknown

SUMMARY OF OES EVALUATIONS




Study
Effect Size with 95% CI
Weight (%)
1. Letters to Medicare beneficiaries
0.591 [0.019, 1.164]
11.23
2. EHR messages to pregnant women
-1.494 [-5.590, 2.603]
0.24
4. Letters to adults over 65
0.160 [0.003, 0.317]
79.26
6. Postcards to Veterans
-0.394 [-1.293, 0.504]
4.76
7. Email messages to Veterans
0.400 [-0.580, 1.380]
4.02
8. Bundled clinical reminders for Veterans
1.600 [-1.222, 4.422]
0.50
Overall
0.195 [-0.004, 0.394]
Heterogeneity: $\tau^2 = 0.01$, $I^2 = 4.89\%$, $H^2 = 1.05$
Test of $\theta_i = \theta_j$: Q(5) = 5.42, p = 0.37
Test of $\theta = 0$: z = 1.92, p = 0.05
-10
-5
0
5
10
Percentage Point Change in Vaccination Rate
Random-effects REML model