Volatility and heterogeneity of vaccine sentiments means continuous monitoring is needed when measuring message effectiveness

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Abstract

Background

The success of vaccination programs often depends on the effectiveness of the vaccine messages, particularly during emergencies such as the COVID-19 pandemic. The current suboptimal uptake of COVID-19 vaccines across many parts of the world highlights the tremendous challenges in overcoming vaccine hesitancy and refusal even in the context of a world-devastating pandemic.

Methods

We conducted a randomized controlled trial in Hong Kong to evaluate the impact of seven vaccine messages on COVID-19 vaccine uptake (with the government slogan as the control). The participants included 127,000 individuals who googled COVID-19-related information during July-October 2021.

Results

The impact of vaccine messages on uptake varied substantially over time and among different groups of users. For example, the message that emphasized the indirect protection of vaccination on family members (i) increased overall uptake by 30% (6-59%) in July but had no effect afterwards for English language users; and (ii) had no effect on overall uptake for Chinese language users throughout the study. Such volatility and heterogeneity in message effectiveness highlight the limitations of one-size-fits-all and static vaccine communication.

Conclusions

Epidemic nowcasting should include real-time monitoring of vaccine hesitancy and message effectiveness, in order to adapt messaging appropriately. This dynamic dimension of surveillance has so far been underinvested.

Trial registration

The study was registered at ClinicalTrials.gov (NCT05499299).

Background

Vaccine hesitancy refers to the reluctance or refusal to get vaccinated despite the safety, effectiveness and availability of vaccines [1]. The growing global epidemic of vaccine hesitancy threatens to reverse the worldwide progress made over the past few decades in controlling vaccine-preventable diseases (VPDs) [2, 3]. The current suboptimal uptake of COVID-19 vaccines across many parts of the world highlights the tremendous challenges in overcoming vaccine hesitancy and refusal even in the context of a world-devastating pandemic that has killed millions and caused trillions of economic losses worldwide [4].

Vaccine hesitancy emerges and spreads for a myriad of complex social, political and cultural reasons, including: (i) complacency against the threat of VPDs [5]; (ii) lack of confidence in vaccine safety and effectiveness[5]; (iii) inconvenient access to vaccine information and vaccines [5]; (iv) exposure to vaccine misinformation, particularly those messages aimed at generating confusion and conflict [6]; and (v) distrust in health authorities and the institutions responsible for developing and delivering the vaccines [7]. The specific root causes of vaccine hesitancy are highly diverse among different individuals and vary across time, locations, and demographics [8]. Recent studies from the US and Europe have reported evidence that the effectiveness of interventions against vaccine hesitancy could also be volatile over time and heterogeneous across subpopulations [1]. Bokemper et al reported that vaccine messages that increased willingness to take a vaccine at one point in time might not be effective in the future even within the same target group [9]. Whilst Dai et al found that text-reminders that induced feelings of ownership over vaccination increased vaccine uptake [10], Rabb et al found no evidence that the same strategy was effective when implemented during later stages of the pandemic [11]. Steinert et al reported striking heterogeneity in vaccine hesitancy and responses to different messages across eight European countries [12]. There is no published evidence to indicate whether message effectiveness is also volatile and heterogeneous in non-English/non-Western context. Here, we present results from a randomized controlled study conducted with 127,000 internet users in Hong Kong to fill this evidence gap.

Since the emergence of the COVID-19 pandemic in January 2020, Hong Kong (population 7.4 million) has adopted a dynamic zero-COVID policy comprising universal mask wearing, stringent importation controls, case-finding and mandatory isolation, contact-tracing and mandatory quarantine, community-wide mandatory testing, prolonged school closure, extensive bans of large-scale events, etc. As of 31 December 2021, such stringent public health and social measures (PHSMs) have enabled Hong Kong to contain four successive waves of COVID-19 epidemic (caused by the ancestral, Alpha and Delta variants) and keep the total number of confirmed cases and deaths at 12,631 (< 2 per 1,000) and 213 (< 3 per 100,000), respectively (Fig. 1A). Consequently, Hong Kong was practically infection-naïve at the population level (< 1% cumulative infection attack rate) before the importation and spread of Omicron in 2022.

Since February 2021, both mRNA (BNT162b2 [Fosun Pharma-BioNTech]) and inactivated (CoronaVac [Sinovac, Beijing, China]) vaccines have been available to Hong Kong residents for free via the online booking system managed by the Office of Government Chief Information Officer (OGCIO). However, as of 1 July 2021, vaccine uptake remained low, with only 31% and 21% uptake of the 1st and 2nd dose (Fig. 1B), partly due to the low local case counts and apparent success of repeated epidemic containment. To increase vaccine uptake, the government and numerous business organizations introduced various measures and incentives to encourage vaccination, including post-vaccination paid-leaves, lotteries with prizes worth up to millions of Hong Kong dollars for those vaccinated (Table S1), exemption from mandatory testing for those vaccinated (Table S2), etc. No evaluation has been done to assess and monitor the impact of these incentives on vaccine uptake, i.e., there is a lack of evidence on their effectiveness.

Sometimes people are labelled dichotomously as anti-VAX or pro-VAX, but studies suggested vaccine hesitancy is a spectrum [13, 14], meaning that vaccine-hesitant individuals are a heterogeneous group that are indecisive to varying degrees about specific vaccines or vaccination in general. In the past decades, communication and behavioral experts have successfully employed nudges to promote prosocial behaviors including vaccination targeting vaccine-hesitant individuals [15–17]. Since the beginning of the COVID-19 pandemic, an increasing number of experimental studies have been conducted to assess the impact of nudging. For example, several studies found that people considered messages that focus on others, especially the elderly and young people, as more persuasive than self-focused messages [18–20]. However, other studies [21–23] reported mixed-results and found that such messages had no promoting effect and could even induce a backfire effect [24]. Few studies have evaluated the influence of nudges on COVID-19 vaccination intention in a non-Western context. In this study, we devised and framed the following seven information vaccine messages (e.g., gain versus loss, self versus group) based on the local Hong Kong socioecological context (e.g., individual/relationship/societal) and health belief model perspective (e.g., perceptions/cues):

1. *'Persuasion'*, which was the government slogan for the COVID-19 vaccine campaign in 2021. This was the control arm. *[Societal/Cue to act]*
2. *'Comparison'*, which emphasized that vaccine uptake in Hong Kong substantially lagged behind that in comparable populations such as Singapore and the UK. *[Societal/Cue to act]*
3. *'Reopen'*, which prompted people to get vaccinated to help Hong Kong reopen sooner. *[Societal/Perceived benefits]*
4. *'Family'*, which prompted people to get vaccinated in order to protect their family. *[Relationship/Perceived benefits]*
5. *'Exemption'*, which emphasized that vaccinated people could be exempted from some disruptive control measures such as mandatory testing (Table S2). *[Self/Non-monetary reward]*
6. *'Lottery'*, which prompted people to get vaccinated in order to be eligible for the numerous COVID-19 lotteries in Hong Kong (Table S2). *[Self/Monetary reward]*
7. *'Mortality'*, which emphasized that COVID-19 has caused millions of deaths worldwide. *[Self/Perceived risks]*

Using Google Ads, we conducted a randomized controlled trial (RCT) to evaluate the impact of these seven vaccine messages of different themes on COVID-19 vaccine uptake in Hong Kong during the July-October 2021 period. Individuals who googled COVID-19 information in Hong Kong (see Table 1 for the keywords of our Google Ads) were randomized to see one of the seven ads and, if they clicked on the ads, the corresponding vaccine message on our website (Fig. S1-S7). We stratified these users by the language used in their search, namely Traditional Chinese, Simplified Chinese, and English. The daily number of ads shown was capped by our daily budget of around US$25 for each language (Fig. S8), i.e., only a small fraction of eligible Google users would be exposed to our ads and multiple exposure was unlikely.

Table 1
Keywords used in the Google Ads for our RCT.

Language used	Keywords
Traditional Chinese	, ,
Simplified Chinese	, ,
English	vaccine, infection, transmission, negative, positive, COVID, SARS-CoV-2, vaccination, test, PCR, novel, SARS, pneumonia, antibody, corona, virus, case, confirmed, diagnosis, reported case, assay, mask, drug, fever, Pfizer, Comirnaty, Fosun, headache, cough, disease, face, acute, inflammation, symptoms, medicine, side effects, ache, pharma, droplet, vaccination, antigen, Coronavac, Sinovac, injection, spread, confirmed case, vial, protect, home, family, loved ones, elderly, senior, child, kids, school, student, meet, social, visit, activity, friendly, gathering, social distancing, beach, swim, diving, hiking, restaurant, party, sunshine, sunbath, surf, gym, holiday, exercise, sunlight, reopen, open, access, destination, oversea, travel, vacation, mainland, China, Beijing, Shanghai, Guangzhou, Shenzhen, France, Paris, UK, South Korea, Korea, Seoul, Japan, Tokyo, Kyoto, New York, London, Amsterdam, Australia, Sydney, Melbourne, Philippines, Indonesia, India, US, Europe, New Zealand, Bali, trip, journey, lucky draw, free apartment, airline, flight

We assumed that a substantial proportion of individuals who clicked through our Google Ads were not apathetic or antagonistic about getting vaccinated. For example, they might be vaccine-hesitant and were searching online for information regarding the necessity, safety, and effectiveness of COVID-19 vaccines. We nudged these individuals to get vaccinated with our vaccine messages and prompted them to take immediate action by scheduling an appointment via the embedded weblink to the online booking system (see Fig. S1-S7). We recorded the IP address of each message delivery and tracked the vaccination bookings made from that IP address afterwards (compiled and anonymized by OGCIO).

Methods

Our study participants included individuals who used the keywords shown in Table 1 in their Google searches between 16 July and 31 October 2021 in Hong Kong. These keywords were chosen because of their relevance to COVID-19, vaccines, and the themes of the seven messages in our study. If the participants clicked on the ads, they were directed to our website and randomized to see one of the seven messages. Individual-level demographic information were not available from Google (despite multiple attempts to access such information via its Hong Kong office). The exposure (vaccine message viewed) and outcome (vaccination booking) were linked by matching the time and IP address of vaccine message delivered logged by our website and that of vaccination bookings maintained by OGCIO. The OGCIO dataset contained the age, vaccine dose, vaccine type and vaccination date of each booking. We used the age information in the OGCIO vaccination booking to age-stratify the impact of vaccine messages on vaccine uptake.

Vaccine message design. The vaccine messages in the six experimental arms were designed to address: (i) different nudges to increase prosocial and/or altruistic behavior; and (ii) different factors for getting vaccinated, as set out by health belief model[25], a social psychological health behavior change model developed and widely used to explain and predict vaccination intention. A similar approach testing different types of messaging has been used in campaigns for HPV vaccination, anti-smoking campaigns, and COVID-19 prevention behaviours [26]. In particular, we adopted the health belief model with a socioecological perspective (i.e. individual or relationship or societal) when developing the six vaccine messages in our study (Fig. S2-S7), which could be classified in terms of the message strategies as follows: cue to act for society: '*Comparison*'; perceived benefits for society: '*Reopen';* perceived benefits for close relationship: '*Family*'; non-monetary reward for self: '*Exemption*'; monetary reward for self: '*Lottery*'; and perceived risks for self: '*Mortality'*.

Statistical analysis. Let $N_{j,k}$ be the number of messages delivered in study arm *j* during the time period *k* and $Y_{i,j,k}$ be the number of bookings following the *i*-th message delivered. We assume that $Y_{i,j,k}$, $i = 1, \ldots, N_{j,k}$, were independent and identically distributed with mean $\mu_{j,k}$ and standard deviation $\sigma_{j,k}$. Given the large sample sizes in our study, we used the Central Limit Theorem to estimate $\mu_{j,k}$ assuming that $\sigma_{j,k}$ was the same as the sample standard deviation. That is, given the observed number of bookings following each message delivery, $y_{i,j,k}$, $i = 1, \ldots, N_{j,k}$, the likelihood function was

$$L\left(\mu_{j,k}\right) = \frac{1}{s_{j,k}\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\mu_{j,k} - m_{j,k}}{s_{j,k}}\right)^2\right)$$

where $m_{j,k} = \frac{\sum_{i=1}^{N_{j,k}} y_{i,j,k}}{N_{j,k}}$ was the sample mean and $s_{j,k} = \sqrt{\frac{\sum_{i=1}^{N_{j,k}}\left(y_{i,j,k} - m_{j,k}\right)^2}{N_{j,k} - 1}}$ was the sample standard deviation. We assumed flat prior for $\mu_{j,k}$. Hence, the posterior distribution of $\mu_{j,k}$ was simply a normal distribution with mean $m_{j,k}$ and standard deviation $s_{j,k}$.

The effectiveness of the message in study arm *j* with respect to the control arm in time period *k* was simply $\mu_{j,k}/\mu_{control,k} - 1$, the posterior distribution of which was

$$P\left(\mu_{j,k}/\mu_{control,k}-1<z\right)=\int_{0}^{\infty}F\left(\left(z+1\right)v\right|m_{j,k},s_{j,k}\left.\right)f(v|m_{control,k},s_{control,k})dv$$

where $f(\bullet|m,s)$ and $F(\bullet|m,s)$ were the pdf and cdf of a normal random variable with mean m and standard deviation s.

Results

For each message delivered to a given IP address, the primary outcome was the number of bookings made from the same IP address within *X* = 6 hours after message delivery; similar results were obtained if we considered *X* = 3 or 12 hours instead (see Fig. S9-S10). Let $\mu_{j,k}$ be the expected number of bookings following each message in study arm *j* during time period *k*. The impact of the message in study arm *j* on vaccine uptake during time period *k* was $V_{j,k}=\mu_{j,k}/\mu_{control,k}-1$. When interpreting the results, we considered the impact on vaccine uptake to be significant if the 95% credible interval of $V_{j,k}$ excluded 0.

Clickthrough rates, messages delivered and bookings of vaccinations

The clickthrough rate of our Google Ads was around 11%, 7% and 14% for Traditional Chinese, Simplified Chinese, and English language users, respectively, which corresponded to around 158,000, 21,000 and 43,000 page-requests for our vaccine messages (Fig. S8). We focused on the impact of single exposure to distinct messages. As such, for any given page request at time *t*, we excluded it from our analysis if there were other page requests from the same IP address during $[t-\mathit{\Delta},t+\mathit{\Delta}]$ (e.g., if the user reloaded the page). We considered $\mathit{\Delta}=1$ day; similar results were obtained if we considered $\mathit{\Delta}=0.5$ or 2 days instead (see Fig. S11-S12).

After applying the exclusion criteria, our RCT comprised around 92,600, 11,700 and 22,500 messages delivered for Traditional Chinese, Simplified Chinese, and English language users, respectively. For each of these three groups, the number and temporal distribution of messages delivered were very similar across all study arms (Fig. 2A), suggesting that the effect of randomization was largely unaffected by the exclusion criteria.

The expected number of bookings per message delivered in the control arm steadily declined over time from July to October (Fig. 2B and 2C): (i) from 0.28 to 0.12 for Traditional Chinese; (ii) from 0.29 to 0.09 for Simplified Chinese; and (iii) from 0.23 to 0.07 for English. Similar downtrends were present in all the experimental arms. These temporal declines in the number of bookings reflected an increasing level of vaccine hesitancy among the subjects over time, probably because: (i) there were fewer than 100 local cases of COVID-19 throughout our study period which might have progressively reinforced the misperception that COVID-19 was no longer a health threat to the Hong Kong population (contrasted with the sharp rises in vaccine uptake as a massive Omicron wave unfolded in Hong Kong a few months later); and (ii) subjects in later stages of our study had likely been holding out on vaccination for longer and therefore tended to be more vaccine-hesitant (reflected by the plateauing of vaccine uptake in the general population during September-October; Fig. 1C). In view of relatively low uptake in September and October, we merged those two months into a single time period in our subsequent analysis because the respective monthly statistical inference would be highly imprecise otherwise.

Effects of messages

For Traditional Chinese language users, *Comparison*, *Exemption*, *Family*, *Lottery* and *Reopen* increased uptake in July among those aged 12–29 by 33% (11–60%), 27% (6–52%), 28% (6–54%), 22% (1–47%) and 26% (6–52%), respectively (Fig. 3). However, these positive effects in July either vanished or reversed in the following months, potentially because those who could be convinced by these messages had already made their choice. In particular, *Exemption*, *Family* and *Lottery* reduced uptake in August among the same age group by 10% (0–20%), 14% (3–24%), 12% (1–22%), respectively. None of the messages had significant impact on overall uptake in any month except for *Comparison* which increased overall uptake in July by 13% (1–25%).

For Simplified Chinese language users, *Mortality* reduced uptake in July among those aged 12–29 by 40% (1–66%) whilst the other messages had an insignificant effect (i.e., essentially the opposite of their effects for Traditional Chinese language users among the same age group during the same time period) (Fig. 3). During September-October, *Comparison* reduced uptake among those aged 12–29 by 39% (1–65%); *Lottery* increased uptake among those aged over 54 by 152% (7-779%); and *Reopen* increased uptake among those aged 30–54 by 67% (2-192%). None of the messages had a significant impact on overall uptake in any month.

The effect of messages for English language users was drastically different from that for Chinese language users: some messages significantly increased uptake for some age groups at certain time points, but none of the messages significantly reduced uptake among any age group during any time period (Fig. 3). *Family* increased uptake in July among those aged 30–54 by 41% (10–83%). *Mortality* increased uptake in September-October among those aged above 54 by 69% (1-207%). *Exemption* and *Family* increased overall uptake in July by 25% (2–53%) and 30% (6–59%), respectively (although the effects of *Exemption* among each age stratum during this time period were not significant). *Mortality* increased overall uptake in September-October by 23% (1–52%).

Discussion

Taken together, our results suggested that in the context of COVID-19 vaccination in Hong Kong with the government slogan as the comparator, although some vaccine messages prompted an initial increase in uptake for some age groups, none of them consistently increased uptake over time among any given target group. Our results corroborate the contention that vaccine message effectiveness can be volatile over time (e.g., the reversal or vanishing effects of *Exemption*, *Family* and *Lottery* for Traditional Chinese language users between July and August) and heterogeneous among target groups (e.g., some messages reduced uptake among Chinese language users but none of the messages reduced uptake among English language users), reflecting the changing context of the epidemic and response as well as personal experiences and sentiments. The validity of this contention would imply the limitation of one-size-fits-all and static vaccine communication typically adopted by vaccination campaigns (e.g. when there is insufficient time or lack of resources for assessing heterogeneity of vaccine sentiments among different target populations before launching vaccine campaigns). As such, we echo cautions from recent studies regarding the potential risk of extrapolating one-off evidence of message effectiveness through time and across target groups without systemically monitoring their effectiveness in the field [9, 12]. In particular, it would be prudent for public health officials to proactively gather scientific intelligence on target group-specific vaccine sentiments when designing their vaccine communication strategies for future vaccination programs against not only COVID-19 but also other infectious diseases.

Epidemic nowcasting broadly refers to assessing the current state by understanding key pathogenic, epidemiologic, clinical, and socio-behavioral characteristics of an ongoing outbreak [27]. Its primary objective is to provide situational awareness and inform decisions on control responses including vaccine communication. Together with previous studies, our results suggest that volatility and heterogeneity of vaccine sentiments is the norm rather than the exception. As such, epidemic nowcasting should include real-time monitoring of vaccine sentiments and message effectiveness, an essential dimension of surveillance which has been under-investigated or even neglected [27, 28].

Our study has several important limitations. First, our subjects comprised individuals who Googled for COVID-19 information. Although Google is the most popular internet search engine in Hong Kong with more than 90% market share, our subjects were likely to be younger and more tech-savvy compared to the general population. However, any strong bias in our results would actually reinforce our conclusion that the impact of vaccine messages on uptake is highly heterogeneous among population subgroups.

Second, many individuals who googled COVID-19-related information (especially regarding vaccination) were likely to be in the contemplation and preparation stages of the transtheoretical model in the context of getting vaccinated [29]. As such, the primary outcome of our study arms, namely the expected number of bookings following each message delivery (Fig. 2), should not be regarded as the absolute effectiveness of the vaccine messages in general settings (i.e., beyond the context of our RCT) because a significant proportion of our subjects who have made their vaccination bookings would have done so even without seeing our vaccine messages. Notwithstanding, the study showed the influence of various information nudges on vaccination intention among vaccine-hesitant individuals who had not been fully vaccinated at the time of the study despite the safety, effectiveness, and availability of vaccines. Further, our conclusions regarding the volatility and heterogeneity of vaccine message effectiveness were based on the relative changes in primary outcome with the governmental slogan as the control and therefore should be robust against such bias.

Third, although our results clearly showed differential impact of vaccine messages among Chinese and English language users, we could not elucidate the underlying drivers for such heterogeneity due to the lack of individual-level sociodemographic information about the subjects. During 2021, the Google Trends of the search term “side effects” in Traditional/Simplified Chinese peaked during July-August and then drifted significantly downwards in subsequent months, whilst the corresponding Google Trends in English peaked in March-April (Fig. S13). This suggests that differential confidence in vaccine safety might be an explanatory factor for the observed heterogeneity of vaccine message effectiveness between Chinese and English language users in our study.

Fourth, our sample sizes were determined by our daily budget constraint (around US$25 per language) instead of *a priori* statistical power calculations. For our future studies (and more generally the digital surveillance systems that we advocate), sample sizes could be dynamically adjusted in near real time with respect to the latest estimates of effect size in each experimental arm.

Fifth, our study design was unable to support investigation of the impact of multiple exposure to vaccine messages on vaccine uptake. As such, the effect sizes reported here do not reflect fully the potential impact of vaccine messaging on vaccine uptake.

Sixth, given that all participants and vaccination bookings were intractable in our study, we were unable to verify whether participants who viewed our vaccine messages made bookings for themselves or someone else. Nonetheless, assuming that our randomization was effective, all study arms were subject to this problem to the same extent and the inferred differential impact of vaccine messages on vaccine uptake should remain valid, albeit with the caveat that the message viewer and the vaccinee might not be the same person.

Vaccine sentiments are constantly influenced by rapidly evolving epidemiologic, social, and political factors from both local (e.g., the risk of getting infected, etc.) and transborder contexts (e.g., mandatory vaccination for inbound travelers by some jurisdictions). Reaching, understanding, and influencing the vaccine hesitant thus requires continuous and extensive outreach which is a formidable challenge even for the best-resourced populations. The lack of a global, multidisciplinary, sustainable, and translational effort to combat vaccine hesitancy and misinformation has been highlighted by the United Nations General Assembly in April 2021 (https://www.un.org/press/en/2021/sc14438.doc.htm). Infodemics, particularly those fueled by digital misinformation against a backdrop of scientific and social uncertainty, can substantially amplify the volatility of vaccine sentiments and erode public trust in policymakers and health authorities. We posit that in our increasingly digitized world, effective vaccine sentiment surveillance requires dedicated and long-term partnerships between the public health community and the digital tech industry. For example, online search advertising and social media platforms provide a pervasive, scalable, and personalized channel for monitoring and influencing vaccine sentiments among the vaccine hesitant because many individuals who are interested in but hesitant about getting vaccinated would search or browse the internet for answers and advice. Harnessing such potential, however, would require synergistic and complementary collaborations between public health leaders and tech innovators to implement robust, bespoke, and cost-effective surveillance systems (e.g., accounting for biases that often lurk in big data [30, 31]).

Declarations

Ethics statement

The study was approved by the Institutional Review Board of the University of Hong Kong and the Hong Kong Island West Cluster of Hospitals in Hong Kong (HKU/HA HKW IRB, reference number UW21-428) and registered at ClinicalTrials.gov (NCT05499299). Written informed consent was waived by HKU/HA HKW IRB because all the data collected were anonymized and no personal identifiers or data were collected.

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Competing interests:

Authors declare that they have no competing interests.

Data and materials availability:

We collated epidemiological data from publicly available data sources (https://data.gov.hk/en-data/dataset/hk-dh-chpsebcddr-novel-infectious-agent). All the epidemiological information that we used is available in the main text or the supplementary materials. The anonymized vaccination booking data, including date and time of booking, IP address, type and dose of vaccines, were compiled by the Office of Government Chief Information Officer (OGCIO), The Government of Hong Kong Special Administrative Region. Interested parties can contact OGCIO at https://www.ogcio.gov.hk/en/contact_us/ to make the same data request. Codes used in the paper (with data removed) are available at GitHub after the paper is accepted for publication (https://github.com/kathyleung/).

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Figures

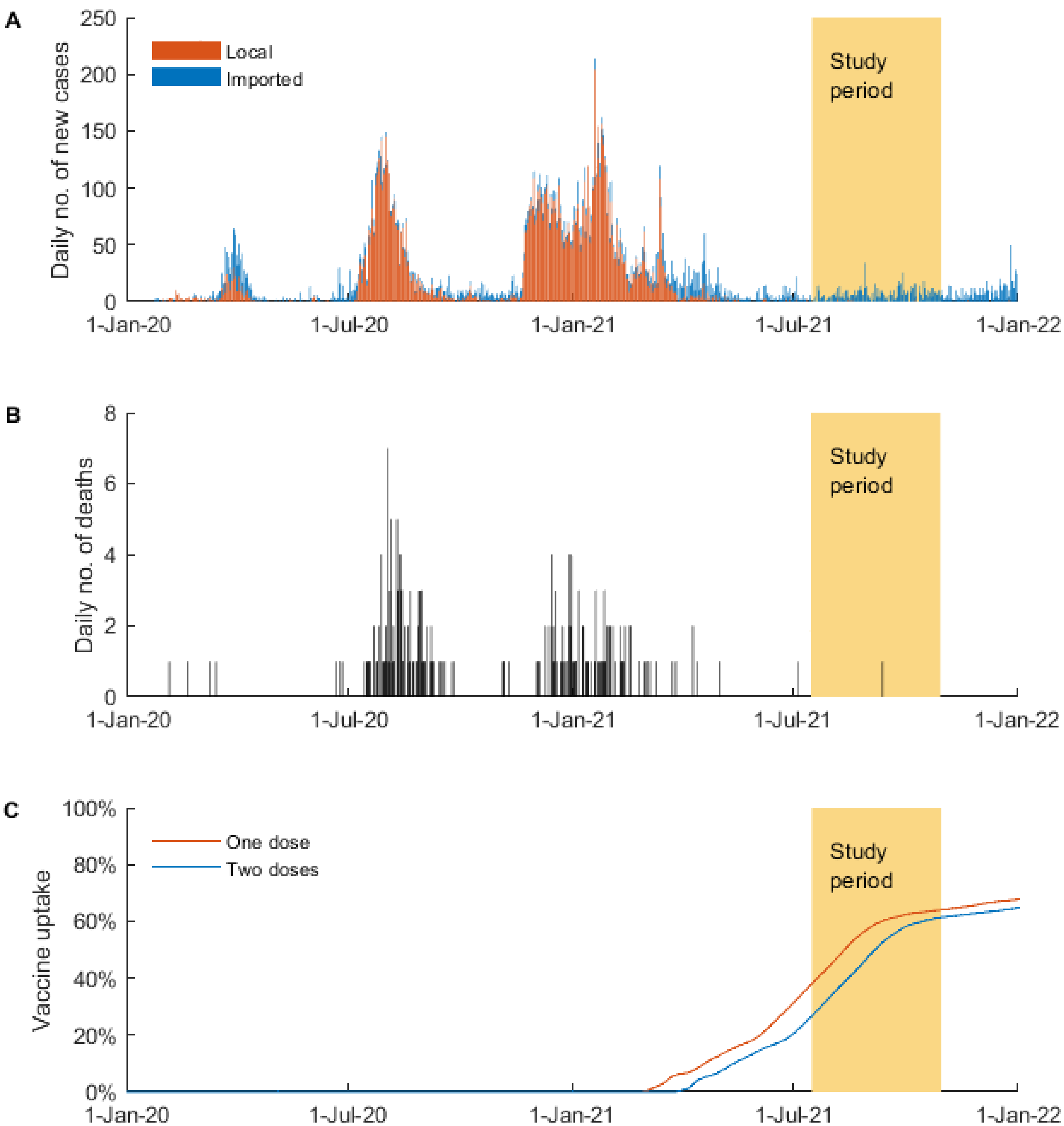

Figure 1

COVID-19 epidemics and vaccine uptake in Hong Kong during 2020-2021. **(A)**Daily number of new cases stratified by local and imported cases. **(B)** Daily number of new COVID-19 deaths. **(C)** Uptake of one or two doses of vaccine.

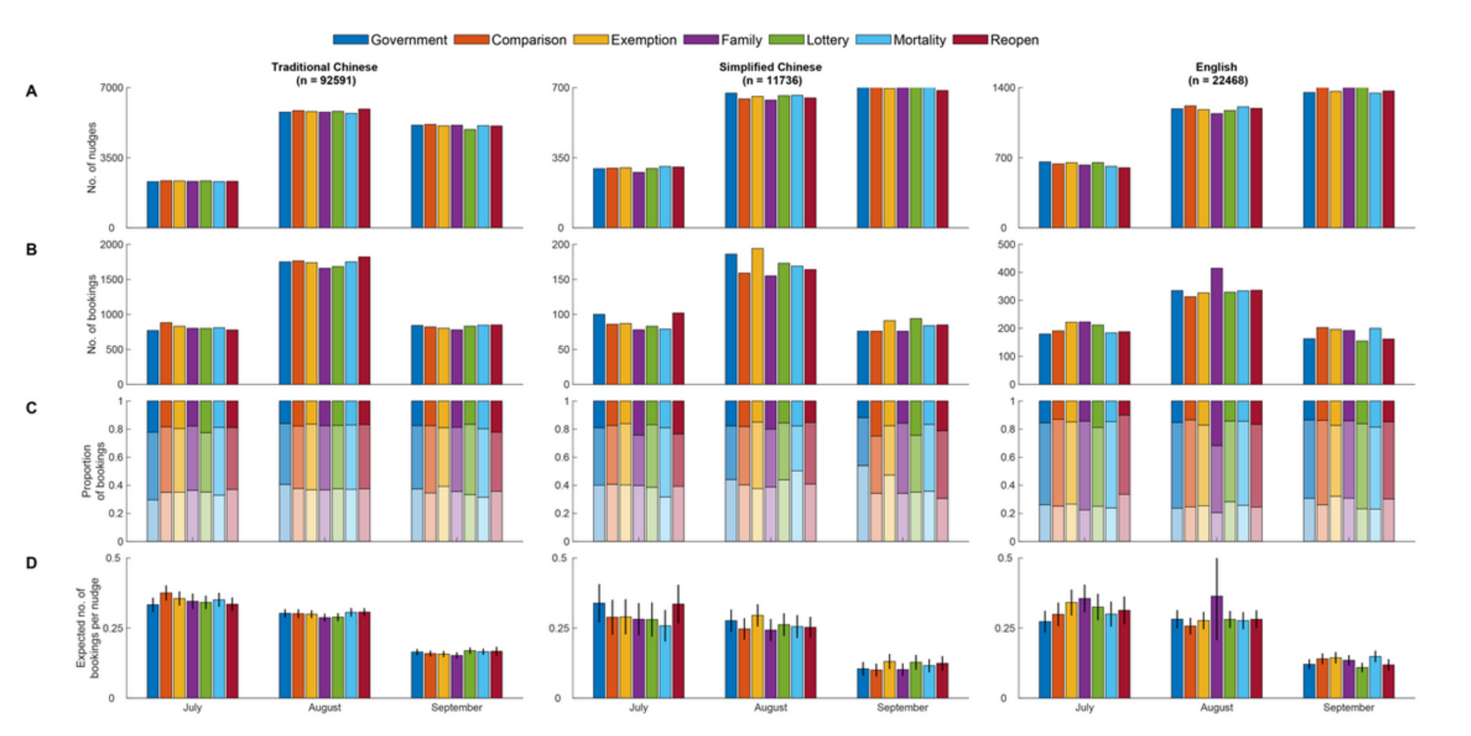

Figure 2

Descriptive summary and primary outcomes of each study arm in the RCT. The primary outcome was the number of bookings made within *X* = 6 hours following each message delivery. (A) Total number of messages delivered. **(B-C)** Total number of bookings registered and the underlying age distributions. Light, medium, and dark shades correspond to those aged 12-29, 30-54 and 55 or above. **(D)** Estimated mean number of bookings following each message delivery. Bars and vertical bars indicate posterior medians and 95% credible intervals.

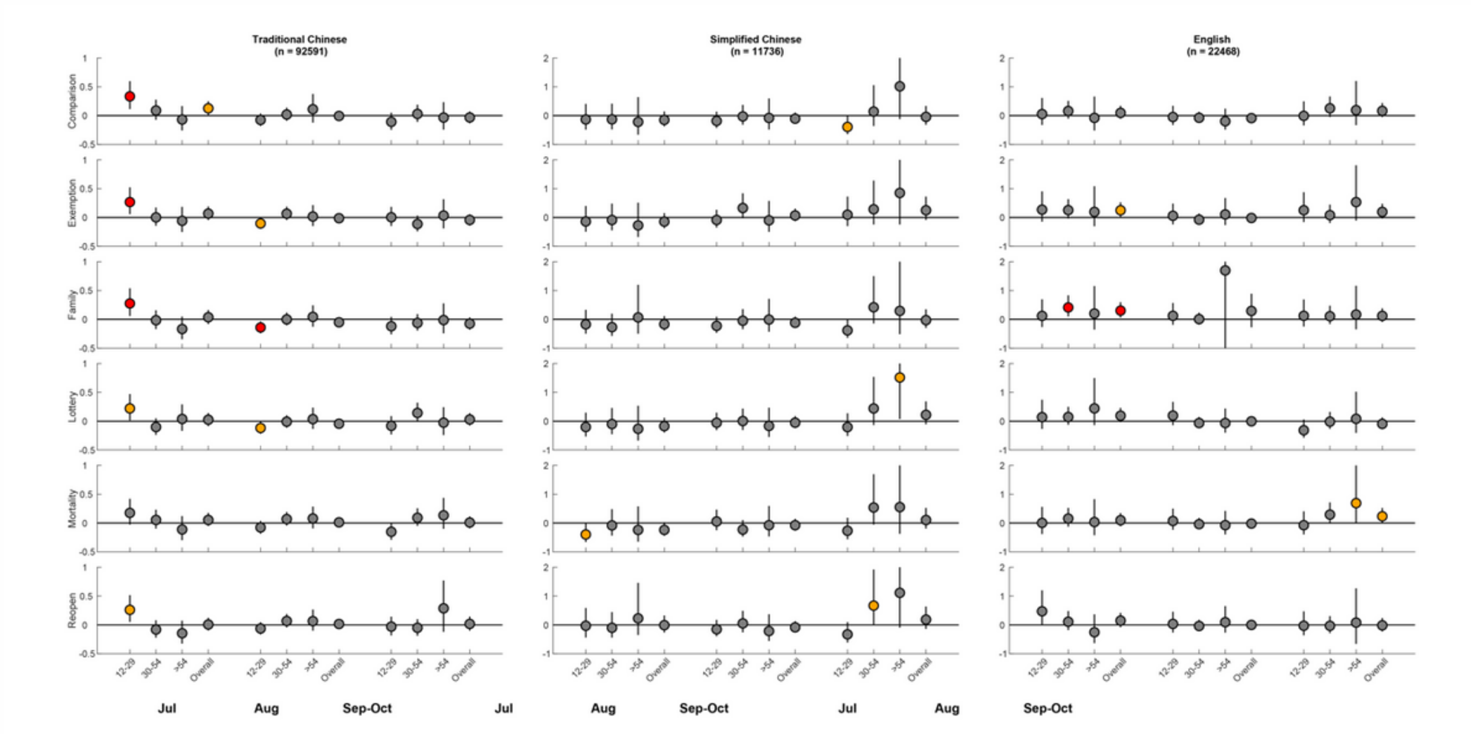

Figure 3

Relative increase in the mean number of bookings made within *X* = 6 hours following each message delivery with the government slogan as the control. Red and orange data points indicate that the corresponding 99% and 95% credible intervals exclude 0.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterials.docx
- 3.ResearchProtocolJTWVAX202101180521v1.pdf