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Effectiveness of SMS reminders to increase demand for HPV immunisation: a randomised controlled trial in Georgia

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Abstract

Interventions informed by behavioural science can help to overcome barriers to childhood vaccination, and increase vaccine uptake, at a low cost to public health authorities. In Georgia, a country with low rates of uptake of the HPV vaccine, we conducted a country-wide RCT that included over 55,000 girls aged 10-12, representing the entire population of eligible unvaccinated girls of this age in the country. Our findings highlight the effectiveness of low-cost interventions, and add compelling evidence to support the use of 'reminder' messages for health services. Working with national public health authorities, we randomised this eligible population of unvaccinated girls into one of five trial arms. Caregivers of the girls in four of the arms were sent different versions of a behaviourally informed SMS reminder, reminding them that their daughter was due to receive the first dose of the HPV vaccine. The control group was sent no SMS reminder. The reminders were sent in September 2022, beginning a 62-day trial period. Our analysis shows that 2,032 girls received the vaccine during the trial, a vaccination rate of 3.76%. This varied from a rate of 2.4% for the control group, to 4.7% for the group that were sent the 'reserved' framing version of the SMS reminder, which was associated with the highest rate of vaccine uptake. Our analysis shows that each version of the SMS reminder was more effective than the control at increasing uptake of the HPV vaccine, with 'reserved' framing the most effective.

JEL codes: D91, I12, C93

Keywords:

- vaccination; nudge; field experiment; randomised control trial; human papillomavirus

1. Introduction

The human papillomavirus (HPV) vaccine helps protect against cancers caused by HPV infection. HPV can cause a number of cancers, notably causing over 95% of cervical cancer (WHO, 2022a). In Georgia, a transcontinental former Soviet state at the intersection of Eastern Europe and Western Asia, cervical cancer is the 3rd leading cause of female cancer death (NCDC, 2020). The HPV vaccine was first piloted in the country in 2017, in three large cities (Tbilisi, Kutaisi and Batumi) and then added to the national vaccination schedule for girls aged 9-13 in mid-2019 (as per the national calendar, girls aged 9 to 13 are eligible to receive the vaccine, while there is also currently a state 'catch up' program which extends the eligibility criteria to the age of 18). It is possible that achieving adequate HPV vaccination coverage will allow cervical cancer in Georgia to be virtually eliminated over time (Palmer et al., 2019). However, while the data on HPV vaccination in the country is limited, all sources concur that coverage remains low, and that it fell over the course of the Covid-19 pandemic. Indeed, while the WHO (World Health Organisation) and UNICEF (United Nations Children's Fund) estimate that globally at least 3.5 million children missed the first dose of the HPV vaccine as a result of the pandemic (WHO, 2022b), the problem in Georgia is particularly stark, with joint WHO/UNICEF estimates for coverage of the first dose of the HPV vaccine among 10-14 year old girls in Georgia falling from 38% for 2019 to just 14% for 2021 (UNICEF, 2023). This represents a 63% decrease in the rate of HPV vaccination between 2019 and 2021, which compares unfavourably to what was experienced in other countries during the Covid-19 pandemic. For instance, while decreases of 41%, 24% and 22% were experienced in England, Switzerland, and Greece, other countries such as Israel and Australia saw zero or negligible impact on the rate of HPV vaccination as a result of the Covid-19 pandemic (Lavie et al., 2023. More recent data from the National Center for Disease Control and Public Health of Georgia (NCDC) indicates coverage of 24% for 2021. All indications are that coverage of this potentially life-saving vaccine remains far below adequate (NCDC, 2022).

Behavioural science has been extensively employed to develop and implement strategies to promote vaccine uptake in diverse settings globally. One such strategy is the use of social norms, which entails communicating to individuals the high vaccination rates in their community to encourage conformity (Brewer et al., 2017a). Another effective approach is the use of incentives, such as gift cards and lotteries, to incentivise vaccine uptake (Campos-Mercade et al., 2021). Behavioural science has also been leveraged to address vaccine hesitancy by identifying and addressing the underlying beliefs and concerns that

prevent people from getting vaccinated. For example, informative and emotionally resonant messaging has been shown to be effective in addressing concerns about vaccine safety (Brewer et al., 2017a). Additionally, behavioural science has facilitated the development of interventions that aim to reduce barriers to vaccination, such as waiting times, to make the vaccination process more convenient and accessible. These strategies have demonstrated effectiveness in increasing vaccine uptake and continue to play an integral role in global vaccination efforts. Recognising the role that behavioural science has to play in encouraging vaccine uptake, in 2022 the WHO published extensive guidance documentation entitled '*Behavioural and social drivers of vaccination*' (WHO, 2022c).

Some of the most promising evidence in high-income countries exists for nudges that offer incentives to parents and healthcare workers, that make information more salient or that use trusted messengers to deliver information (Reñosa et al., 2021). Specifically, there is growing evidence from the USA and other high-income countries in recent years that nudges (in particular those that are SMS-based) can be a successful and cost-efficient method of encouraging vaccination and attendance at vaccination appointments (Staras et al., 2021; Francis et al., 2017; Mavundza et al., 2021), with framing indicating that a vaccine has been "reserved" for the individual (or someone in their care) found to be particularly effective in some instances (Milkman et al., 2022; Milkman et al., 2021; Buttenheim et al., 2022). However, evidence outside of the United States (and English-speaking countries in general) has remained relatively scarce. Given this, a large-scale randomised control trial (RCT) was carried out as part of efforts by the UNICEF Georgia Country Office to increase HPV vaccination rates in Georgia, in response to the low rates of uptake in recent years. UNICEF partnered with the Behavioural Insights Team (BIT) to explore behavioural barriers to vaccination in the country, and to develop and test solutions informed by this, noting that there was no guarantee that results seen in other settings would be replicated in the Georgian context.

1.1 Randomised Control Trial

This RCT utilised the full cohort of 55,176 Georgian girls aged 10-12 who were both eligible to receive their first dose of the HPV vaccine and had at least one caregiver contact number associated with them in the public health database. The trial tested the impact of four behaviourally-informed SMS reminder messages sent to their caregivers, against a control in which no SMS reminder was sent. The four versions of the SMS reminder were chosen as they build on promising evidence from more than a decade of research in this area, and

address the specific barriers identified during earlier exploratory work (namely the fact that caregivers did not previously receive reminders that their daughter was due for HPV vaccination). The reminders are heavily informed by the recent behavioural science literature, and emulate other SMS and non-SMS based nudges to encourage vaccination in the United States of America and other high-income countries (Milkman et al., 2011; Tull et al., 2019; Wynn et al., 2021), within a context (non-English speaking, former-Soviet country) where such evidence is limited . More specifically, recent evidence suggests a high acceptability among caregivers for mobile-phone reminder interventions to improve routine childhood immunisation coverage and timeliness (Eze et al., 2021a; Menzies et al., 2020). Where knowledge of the vaccine schedule is modest, reminder and recall messages can be effective at bridging the information gap and encouraging patients and/or their caregivers to take up the offer of immunisation (Obi-Jeff et al., 2021). Indeed, recent evidence from low- and middle-income countries (such as Georgia), although with significant heterogeneity, suggests that SMS reminders can contribute to achieving high and timely childhood immunisation coverage (Eze et al., 2021b). A Cochrane review of patient reminder and recall interventions to improve vaccination rates included a meta-analysis on 55 studies with 138,000 participants which estimated that such interventions increase uptake by an average of 28% in relative terms (Jacobson-Vann et al., 2018). It is worth noting that while the vaccination schedule for the HPV vaccine includes two doses, by working with girls who were unvaccinated before the trial, the SMS reminder and trial more generally focuses only on uptake of the first dose of the HPV vaccine - we do not have data to comment on the impact of the intervention on uptake of the second dose of the vaccine.

1.2 Details on intervention: SMS reminders

From January 2022, four versions of the SMS reminder were designed, based on evidence from the behavioural science literature and the barriers to HPV vaccination in Georgia, identified during earlier exploratory work (namely the fact that caregivers did not previously receive reminders that their daughter was due for HPV vaccination). The four versions of the SMS reminder, to be tested against a control (no SMS reminder), were as follows: (1) a short simple reminder message with no additional information; (2) a reminder message with a link to the seduction of the National Center for Disease Control (NCDC)’s website that provides information about HPV vaccination; (3) a reminder message with the NCDC link and "reserved for her” framing; and (4) a reminder message with the NCDC link and additional safety information about the HPV vaccine. The English-language wording of each reminder

message can be seen in Table 1, which also contains a description of applicable concepts from behavioural science associated with each version of the SMS reminder.

These SMS reminder messages were formulated by BIT, and then carefully translated into Georgian by the UNICEF Georgia country office, with specific care to maintain the integrity of the insights from behavioural science being employed. The Georgian-language versions used in the trial can be seen in Table E1 in the Appendix. Following finalisation of the intervention messages, BIT and UNICEF worked with NCDC to implement the intervention through the national SMS reminder system for vaccination, supported by the Information Technology Agency (ITA) in Georgia. This involved identifying the population of girls eligible to receive the HPV vaccine (e.g. those aged 10-12 who have not yet received the first dose of the HPV vaccine) with the mobile phone number of at least one caregiver in the national e-health system database. The target population was then randomised into five groups, in which the girls' caregivers would receive either no reminder (control) or one of the four versions of the SMS reminder (treatment). The NCDC and ITA then sent the SMS reminders using their national SMS system, according to group allocation, on 15th September 2022. Recipients of the SMS reminders saw the sender ID as "NCDC.ge" ('ge' being the 2-letter ISO country code for Georgia), further indication that the SMS was sent from an official source.

This trial went through an external ethics process: UNICEF applied for, and received, approval from the Institutional Review Board of the Georgian National Centre for Disease Control and Public Health (NCDC). The trial was self-assessed as falling under "Low" ethical risk using BIT's ethics assessment framework. The trial was pre-registered with ClinicalTrials.Gov on 13/09/2022, with the ID *NCT05536674*.

Table 1. SMS reminder messages

Version		SMS reminder message	Applicable concepts from behavioural science
1	**Short SMS with no additional information**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. Contact your polyclinic today to arrange an appointment."*	• **Timely prompt:** behavioural nudge - this is an intervention designed to influence behaviour without restricting choice. The use of SMS reminders as 'timely prompt' nudges has grown in the last decade in particular, as demonstrated for instance by Orr and King (2015). • **Defaults:** The use of the language "*Your daughter is due*…" implicitly assumes that the daughter in question will receive the vaccine, and sets receiving the vaccine as the default option. This builds on research on 'presumptive announcements', such as that by Brewer et al. (2017b).
2	**Short SMS + NCDC link to more information**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. Contact your polyclinic today to arrange an appointment. More information on the official NCDC website: [LINK]"*	• **Timely prompt:** as above. • **Defaults:** as above. • **Messenger effects:** source credibility **-** people are often more receptive to messages from sources they believe to be authoritative and credible. This message's reference to the NCDC and its website leverages this effect. 'Source effects' in communications have been researched for at least three decades, as in Wilson and Sherrell (1993).
3	**SMS with "*reserved for her*" framing + NCDC link**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. Her vaccine is reserved for her at the polyclinic. Contact them today to arrange an appointment. More information on the official NCDC website: [LINK]"*	• **Timely prompt:** as above. • **Defaults:** as above. • **Messenger effects:** as above. • **Loss aversion:** People tend to dislike loss more strongly than they like gains of equal value. When presented with information that a vaccine has been reserved for their daughter specifically, parents may feel more strongly encouraged to avoid missing a specific or limited opportunity. The effects of 'loss-framing' within public health specifically has been well researched over several decades, for instance in Gallagher and Updegraff (2012).
4	**SMS with safety information + NCDC link**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. The vaccine has been given safely to more than 118 million girls worldwide. Contact your polyclinic today to arrange an appointment. More information on the official NCDC website: [LINK]"*	• **Timely prompt:** as above. • **Defaults:** as above. • **Messenger effects:** as above. • **Social norm / social proof:** Although uptake of the HPV vaccine in Georgia is low, this message provides social evidence that more than 118 girls globally have safely received the vaccine without adverse effects. This uses the principle of social norms, as parents may be influenced by the idea that many others have had the vaccination, making it a socially accepted and recommended behaviour. The effects and application of social norms has been extensively researched over many years, see for example Deutsch & Gerard (1955).

2. Methods

2.1 Research aims and hypothesis

Our hypothesis stated that the SMS reminders would increase the uptake of HPV vaccination. As outlined in the Introduction, there is well-documented evidence that patient reminder and recall interventions to improve vaccination rates can increase uptake by several percentage points. All five versions of the SMS reminders were designed based on evidence from behavioural science and the barriers to HPV vaccination identified during the first phase of the project. Academic literature on similar interventions in other settings indicates that the “reserved for (her)” framing such as that used in version 3 of the SMS reminders may be the most effective in terms of increased uptake of the HPV vaccine [15,16]. However, given the lack of evidence from settings such as the one the intervention was launched in, we were agnostic as to which version would be most effective in increasing vaccination rates in this specific study.

2.2 Participant selection and eligibility

Participants in the trial were the caregivers of eligible girls (e.g. those aged 10-12 who had not yet received any doses of the HPV vaccine, with at least one caregiver’s mobile phone number in the e-health system). The NCDC/ITA identified the eligible population by filtering the NCDC Immunization e-module & ITA e-health system based on the data fields: gender, age, HPV vaccination status, and availability of a caregiver’s phone number. The total national population of girls aged 10-12 within the NCDC database was 89,821 as of August 2022. Of these, 69,717 had not received the HPV1 vaccine, implying a vaccination rate of **22.4%** for this cohort. Caregiver contact numbers were available for **55,176** of these 69,717 girls. This group of 55,176 girls was the eligible population of interest, having 1) an age between 10-12, 2) not yet received any doses of the HPV vaccine, and 3) at least one caregiver’s mobile phone number in the NCDC database. Based on previously published meta-analysis [25], our power calculations indicated that for all comparisons (any treatment arm vs. control), the anticipated effect size was a 28% relative increase in uptake of the first dose of the HPV vaccine, between the treatment and control conditions. For instance, assuming a base rate of vaccination of 3% during the trial period, a relative increase of 28% would amount to a 0.84 pp increase in the take up of the first dose of the HPV vaccine, to a rate of 3.84%.

A full participant flow and exclusion diagram for enrollment, allocation, and analysis can be found in Figure A1 in the Appendix.

2.3 Randomisation

The eligible population was randomised at the individual level, into five groups (each of n=11,035, with one n=11,036) using the following simple randomisation steps:

1. Each eligible girl in the sample was allocated a unique ID
2. Each eligible girl was assigned a number between 1 and 5 (the number of trial arms) randomly.
3. The caregiver(s) of each eligible girl were sent one of the four versions of the SMS reminder (or no SMS) according to the randomisation allocation outcome.
    - Note that each girl could have up to 4 caregivers associated with them within the NCDC/ITA database (mean n=1.8), with each caregiver having up to 6 telephone numbers associated with them (mean n=1.1). In this sense, each girl could have her caregivers cumulatively receive (the same version of) her assigned SMS reminder multiple times.

2.4 Attrition and accuracy of caregiver contact details

Based on conversations with local partners, we did not anticipate any attrition of note from this study. Whilst it is possible that some of the girls (or their caregivers) could leave the country, or become too unwell to receive the HPV vaccine, during the 62-day trial period, the nature of the intervention and trial (with no way to 'drop out' from receiving the one-time intervention), meant that the main risk to the delivery of the intervention as intended arose prior to implementation. Namely, the NCDC estimated that approximately 20% of caregiver contact numbers within their systems were inaccurate. This was taken into account when deciding upon the required minimum sample size for the trial, which our power calculations indicated to be 46,250, with conservative assumptions (i.e. estimating upwards the number of girls required). Given that this was relatively close to the eligible population of interest within the NCDC/ITA dataset (n=55,176), it was decided to include this full available sample of 55,176 in the trial, thus maximising the sample size. The NCDC's *ex ante* estimate of approximately 20% of caregiver contact numbers being inaccurate turned out to be correct. The dataset indicates that across the four treatment arms, between 78-81% of sent SMS reminders were delivered (i.e. implying that approximately 19-22% of caregiver contact numbers were inaccurate for various reasons, such as being out of date).

2.5 Sample representativeness and balance checks

The target population from the NCDC/ITA database were compared with available population data to check that the sample included in the trial, and each of the trial arms once randomised, are representative of the general population of girls in the country. This was done in three steps, checking a) the representativeness of the overall ITA/NCDC data, b) that those girls excluded from analysis were not unrepresentative of the overall sample, and c) that the final eligible sample was representative of the overall population of Georgian girls of this age. Following randomisation, balance checks were conducted, the results of which can be seen in Appendix C. No evidence of significant bias was found. Randomisation checks were performed immediately post-randomisation, in collaboration with NCDC/ITA, to test that each of the five trial arms were balanced on the key covariates available within the data: age; region; and number of parents/guardians. Checks for each of these covariates indicated that the trial arms were almost identical across each of these covariates - i.e. randomisation was successful. This also applied (*ex post*) to the number of SMS reminders a girl's caregivers were sent as part of the trial, with an even distribution of the number of reminders sent across treatment arms. In summary, the randomisation achieved very well-balanced trial arms across all available covariates, the results of which can be seen in Appendix C.

2.6 Data cleaning

NCDC/ITA sent the SMS reminders using their national SMS system, according to group allocation. These SMS reminders were sent in four batches (one for each group of n=11,035 in each trial arm) on 15/09/2022, between 11am-1pm local time. Data collection then occurred 62 days later, on 16/11/2022. The primary outcome was a girls' HPV vaccination status as at this date. This data was linked to the intervention arm the caregiver was allocated to via the girl's unique ID within the NCDC's e-health database. Data cleaning steps included the exclusion from analysis of the following cohorts of girls, to ensure that the analysis was performed on the eligible population of interest only:

- Girls who had already received a dose of the HPV vaccine before 16/09/2022 (n=969, of which 193 were in the control group)
    - The reason that there were (contrary to the design of the trial) in fact some girls within the dataset who had already received a dose of the HPV vaccine by the date the SMS reminders were sent (15/09/22) is twofold. Firstly, the NCDC/ITA confirmed that there has historically been a variable, and sometimes large, lag between the date of

vaccination and the date of the vaccination being recorded within the NCDC's e-health records. Thankfully this lag has been reduced to less than 30 days for vaccinations that have occurred since mid-2022 onwards, however some legacy vaccinations (occurring before mid-2022) were only recorded within the system between late-August 2022 (when the sample was drawn) and trial launch in mid-September 2022. Secondly, there were some vaccinations that actually occurred between these two dates. When these two factors are taken together, it required the exclusion of 968 girls from the dataset (1.8% of girls in the overall sample).

- Girls who had no ID within the dataset (n=78)
    - These 78 girls should not have been included in the dataset to begin with, and were included due to an unforeseen administrative error. It is suspected by the NCDC and ITA that many of the 78 were foreign-born (and thus did not automatically receive a Georgian health system ID number at birth).
- Girls (erroneously) in the treatment arms who in fact have no caregiver contact number within the NCDC/ITA system (n=103)
    - These 103 girls were erroneously included due to the NCDC/ITA's systems incorrectly identifying part of their ID number(s), or some other numbers within their address, etc., as a caregiver contact number, when they had no such number associated with them in the dataset.

For each of the above exclusions, balance checks were performed, which satisfactorily confirmed that the excluded cohorts were evenly distributed across the five trial arms, and that therefore the exclusions did not risk creating bias within the data to be analysed. An overview of this analysis can be found in Appendix C.

The trial was analysed as ITT (intention-to-treat, i.e. analysis on SMS reminders *sent*, rather than "delivered" or "read"). This is a distinction worth noting, as not all SMS reminders sent would have been ultimately read by caregivers, due to a number of potential factors. For instance, some caregiver contact numbers may have been out-of-date within the NCDC/ITA database (see the above paragraph on *'Attrition and accuracy of caregiver contact details'*), or some caregivers may have simply ignored or deleted the SMS without reading it. Given that we could not reliably account for this, (the girl associated with) any caregiver who was *sent* an SMS reminder was included in our analysis. As the outcome measure (HPV vaccination status as at 16/11/2022) is binary, we estimated the impact of SMS reminders on vaccine uptake using logistic models, with the results detailed in Table B1 in the Appendix.

2.7 Spillover

For practical implementation reasons, randomisation occurred on the individual (girl) level. However, in doing so we acknowledged that there was a chance of contamination across trial arms, given the trial covered a very large sample of caregivers of girls aged 10-12 (with our sample of 55,176 girls containing over 61% of the total population of girls aged 10-12 in Georgia). This individual level randomisation did not take account of siblings within the sample, meaning that two or more eligible girls who happen to be siblings could have been randomised into different trial arms (hence the same caregiver(s) being sent different versions of the reminder, or any/no reminders). A competing but less likely cause of spillovers is that two caregivers who know each other will receive different messages, or one caregiver of the two will receive no SMS messages. Our subsequent analysis found that approximately 17% of girls in the control arm (1,871) had at least one caregiver who had one of the SMS reminders sent to at least one of their contact numbers, which meant that some of the control group were directly exposed to the treatment. If one sister was included in the control group, but another sister(s) included in one of the treatment groups, their common caregiver would have been sent an SMS reminder, with no specific reference as to which daughter the SMS was referring to. This constitutes a relatively significant instance of spillover, meaning that our estimates of the treatment effects from the trial are likely to be conservative, as the caregivers of 1,871 girls (17.0%) from the control group were sent one of the SMS reminders.

3. Results

All eligible girls in Georgia (aged 10-12 years old that had not previously been vaccinated, and had at least one valid caregiver contact number within the NCDC's database) were successfully randomly assigned so that their caregivers would receive one of four behaviourally-informed SMS reminders, or no reminder at all (control group). We found no significant differences in individual characteristics across the five groups (balance checks available in Appendix C). Following the extraction of the data at the end of the 62-day trial period, our analysis shows that 2,032 girls across the full eligible sample received the HPV vaccine during the trial period, representing an aggregate vaccination rate of 3.76% across the 62 days. Fewer girls in the control group received the vaccine than those in the treatment arms (255 girls out of 10,828 eligible for analysis in the control group, a rate of 2.4%, which compares to a mean rate of 4.1% (1,777 girls out of 43,200) across the four treatment arms

(range 3.9%-4.7%). The highest rate of HPV vaccination during the trial was observed amongst the group whose caregivers were sent version 3 of the SMS reminder (4.7%), which used framing indicating that the vaccine was “reserved” for the girl, which is a reproduction of findings in other contexts.

3.1 Intention-to-treat analysis: the effect of sending a BI-informed SMS on vaccination

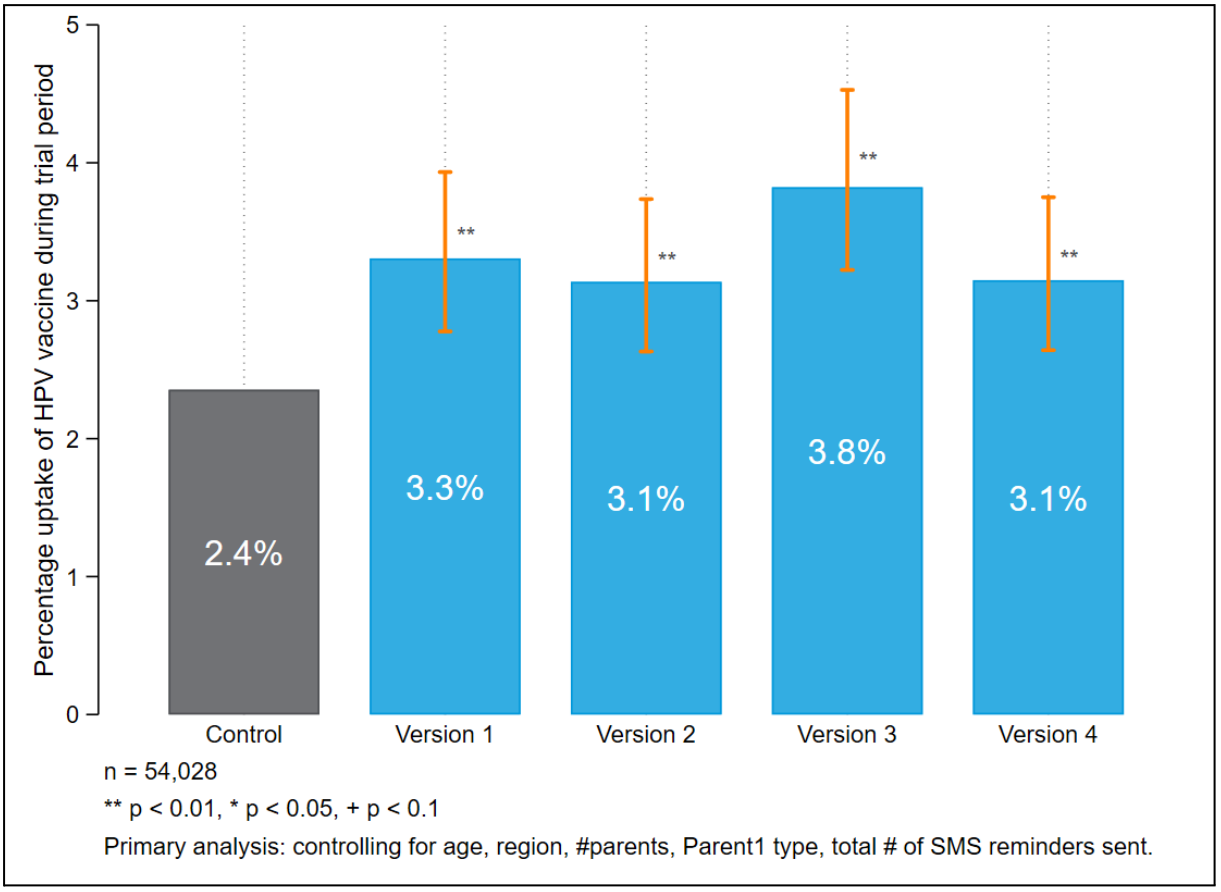
We performed an intention-to-treat (ITT) logistic regression analysis examining the impact of treatment conditions on likelihood of being vaccinated during the 62-day trial period. ITT analysis involves analysing participants based on their initial randomisation to the treatment and control group(s), regardless of whether they received the assigned treatment/control or not. In practice this means that all girls who were assigned to a given treatment group are included in the analysis as such, regardless of whether their caregiver(s) did actually receive the assigned version of the SMS reminder (or were sent no SMS, or a version they should not have been sent according to the trial design). The logistic regression controls for a girl’s age, the number of caregivers she has, the cumulative number of SMS reminders sent to her caregiver(s), her region within Georgia, and the ‘type’ of her primary caregiver (e.g. mother, father, guardian, etc.) to account for the potential impact of these factors on vaccination.

3.2 Findings

Our ITT analysis shows that each of the SMS reminders were more effective than the control (no reminder) in encouraging HPV vaccination during the trial period ($p<0.01$). Figure 1 shows the treatment effect for each version of the SMS reminder, by including the realised vaccination rate for the control group and constructed counterfactual vaccination what *would have* happened if the control group had received that treatment (Figure 1 does **not** display the actual rates of vaccination for each treatment arm, but instead for each bar represents the vaccination rate for the control group *plus* the treatment effect for each version of the SMS as estimated by the ITT regression analysis). Girls whose caregiver(s) were sent version 3 (the SMS with the “*reserved for her*” framing) had approximately 65% greater odds of receiving the vaccine relative to the control group (OR=1.65; 95% CI [1.38-1.97]; $p<0.0001$). Among girls whose caregivers received version 1 (Short SMS), version 2 (Short SMS + NCDC link), and version 4 (Safety information + NCDC link) of the SMS, the odds of receiving the HPV vaccine during the trial were respectively 42%, 34%, and 35% higher

compared to the girls in the control arm. Table B1 in Appendix B shows the full results of our regression analysis, with coefficients expressed as odds ratios.

Figure 1: The effect of sending a behaviourally-informed SMS reminder on HPV vaccination (Intention-to-Treat); 95% CIs (in orange) for treatment group bars (in blue)



3.3 Treatment-on-treated analysis: the effect of receiving a BI-informed SMS on vaccination

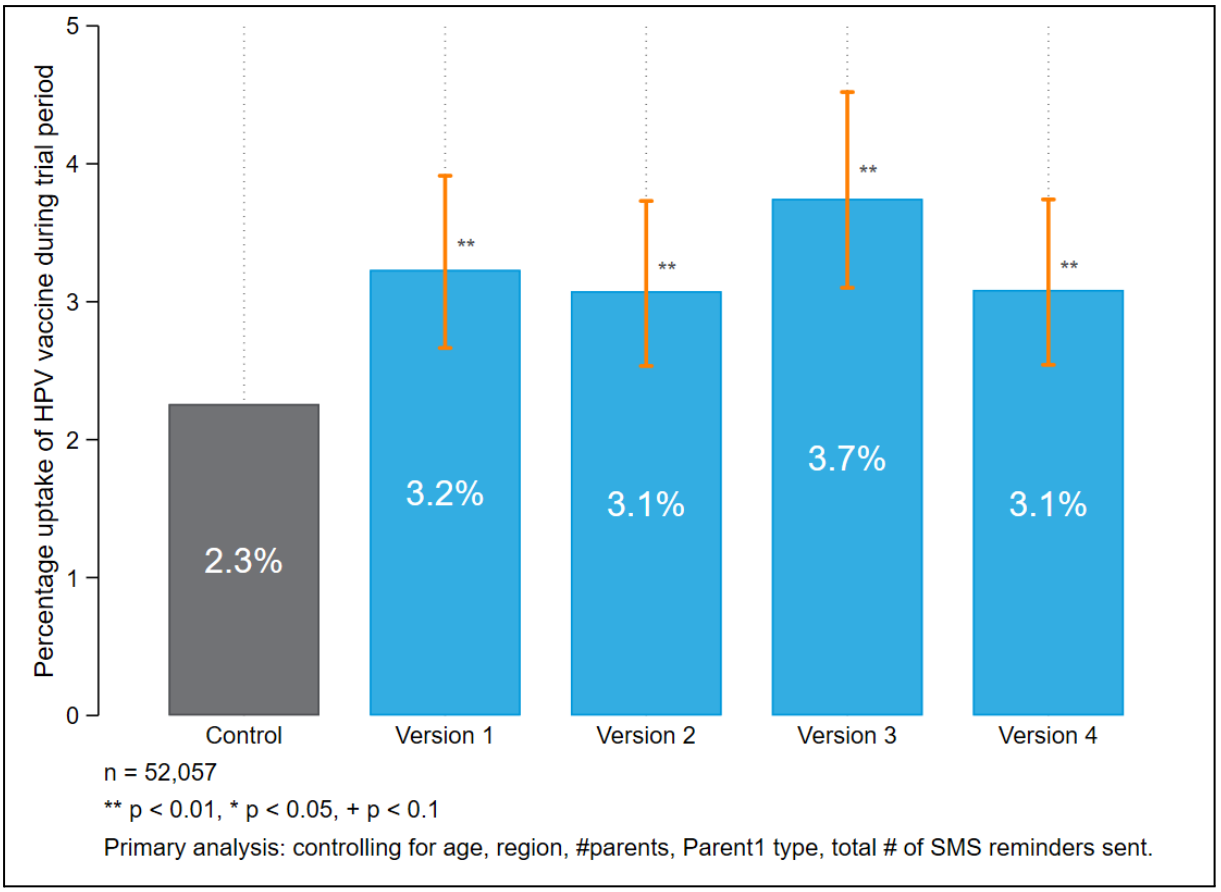
To check the robustness of our results, we also ran the analysis using a 'Treatment-on-Treated' (ToT) approach. ToT analysis refers to analysing only the participants who received and completed the assigned treatment (or control) condition. This approach excludes girls who, for example through some error in SMS dissemination, did not receive the treatment (or control) condition assigned to them during the randomisation process. ToT analysis provides an estimate of the treatment effect in a (large majority) subgroup of girls who experienced their assigned treatment or control condition as intended. For our ToT logistic regression analysis, we excluded: a) 1,841 girls in the control group who had not already been removed from the dataset during data cleaning (see 'Data Cleaning' within the

Methods section above), and who had at least one caregiver who were sent an SMS reminder, due to the fact they shared a caregiver with another girl (e.g. sister) who was assigned to one of the four treatment groups; and b) 130 girls in the treatment groups whose caregiver(s) were sent at least one SMS with no SMS delivering. The exclusion of these girls due to (a) and (b) above does not cause the groups to become unbalanced across any characteristic, and indeed the cohort of 130 excluded from analysis of the treatment groups was evenly distributed across each of the four treatment groups originally.

It is worth noting that the data does not allow us to assess whether the caregiver(s) associated with a treatment-group girl were sent other versions of the SMS reminder (in addition to the correct version as per their treatment group assignment). In the case of (a), this effective spillover of the treatment condition into a large proportion (17.0%) of the control group occurred due to the fact that randomisation into treatment conditions occurred at the individual girl, rather than the family, level. While a low level of effective spillover was anticipated, this was deemed to be tolerable given the considerable difficulty in attempting to randomise at the family level with the NCDC's relatively new national e-health database. In any case, the effective spillover likely means that treatment effects are underestimated within the ITT analysis. This is because within the ITT analysis, the vaccination rate of the treatment groups is not being compared to that of a (control) group which strictly had no members receiving the treatment - in reality almost 17% of the control group were exposed to one of the treatment conditions. Therefore the baseline vaccination rate of 2.4%, against which the treatment conditions have been compared to test for statistical significance, is likely to be somewhat inflated by partial exposure of the control group to treatment conditions.

For the ToT analysis, although excluding this cohort under (a) above does 1) reduce the size of the control group relative to the other groups within the analysis, and 2) imply that girls in the ToT control group are potentially less likely to have sisters than the the girls in the treatment arms, the sample is still sufficiently powered, and the results (and their interpretation) are consistent with the findings from the ITT analysis, as seen below in Figure 2. As can be seen from a comparison of Figure 1 (ITT) and Figure 2 (ToT), the relative effectiveness, and rank, of the SMS reminders under each analytical approach are almost identical (with only some minor changes in percentages), and we can conclude that the results are consistent across the two analyses.

Figure 2: The effect of sending a behaviourally-informed SMS reminder on HPV vaccination (Treatment-on-Treated); 95% CIs (in orange) for treatment group bars (in blue)



3.4 Secondary results: the role of age, numbers of SMS reminders sent, and regional differences

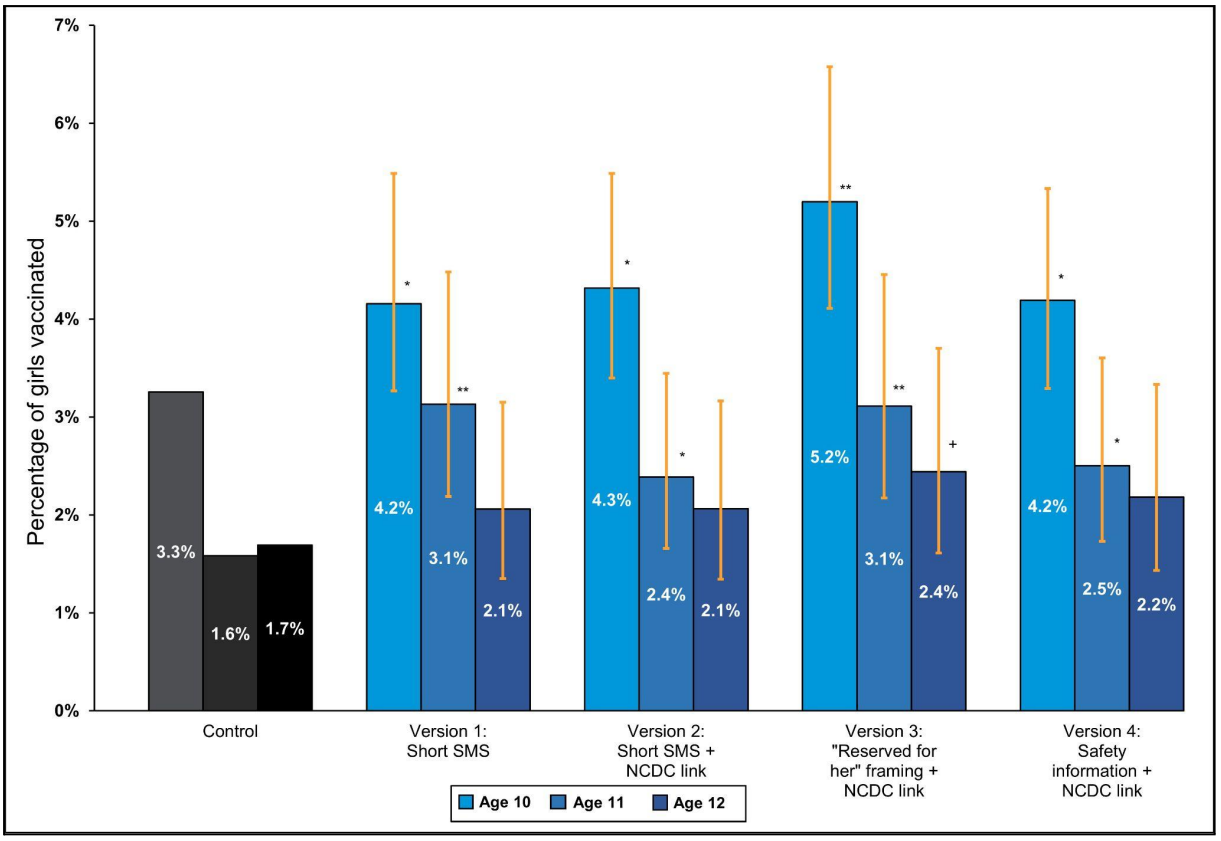
While the primary aim of the trial was to investigate the impact of sending SMS reminders on the subsequent uptake of the HPV vaccine among unvaccinated girls cared for by the recipients of the SMS, our results show that there are other factors that are strongly correlated with HPV vaccine uptake during the trial period. These factors include a girl's age, the number of SMS reminders sent to a girl's caregivers, and the region within the country, and time elapsed within the 62-days trial period. We discuss the first two of these below. The analyses of these factors were not pre-specified, however we found the factors to have had a statistically significant impact on the likelihood of receiving the vaccine.

The results of our logistic regression (Table A2 in the Appendix) show that age also had a statistically significant impact on the likelihood of her receiving the HPV vaccine during the 60-day trial period. The age variable produced an odds-ratio of 0.71 [95% CI = (0.67; 0.76)],

indicating that for each year older a girl within the sample is, she was 29% *less* likely to have received the vaccine. We contend that this can be explained by the fact that girls who were already aged 12 by the time the sample was selected had already been eligible to receive the free HPV vaccine for at least two years, and so the fact that they had not yet received it implies that they were more likely to have caregivers who were in some way reluctant or hesitant towards the vaccine. By contrast, it is more likely that many of the 10-year old girls included in the sample, having only recently become eligible to receive the free HPV vaccine, had not received a vaccine due to a lack of opportunity or planning on behalf of their caregivers, rather than hesitancy towards vaccination itself. While our trial by its nature did not include a measure of baseline motivation of either girls or their caregivers, it is worth noting that recently published analysis has shown that certain types of intervention (informational framing versus salience/convenience framing) can have a greater or lesser impact on (flu) vaccine uptake, based on individuals' baseline motivation to adopt the encouraged activity (receive a vaccine) (Brody et al., 2023). We believe that each of the four versions of the SMS reminder in our trial have both informational and convenience/salience elements, and that the most effective version (version 3, with "*reserved for her*" framing) goes beyond this by using personalisation. In short, without the requisite data it would be challenging to disaggregate the interactions between caregiver motivation and SMS reminder type within our trial, and so the above contention (regarding the different motivation/hesitancy levels of caregivers across girls' age groups) is as far as we postulate.

Furthermore, we can see from Figure 3 that this age effect is not driven by the different versions of the SMS reminders having more/less impact on caregivers depending on the age of the girls in their care. When the primary analysis is run separately for each age cohort (10 year-olds, 11 year-olds, 12-year olds), the relative effectiveness of the SMS reminders does not change across cohorts. In short, version 3 (the SMS reminder with the "*reserved for her*" framing) is the most effective SMS for caregivers regardless of the age of the girl in their care.

Figure 3: Vaccination rate by trial arm, disaggregated by age, intention-to-treat



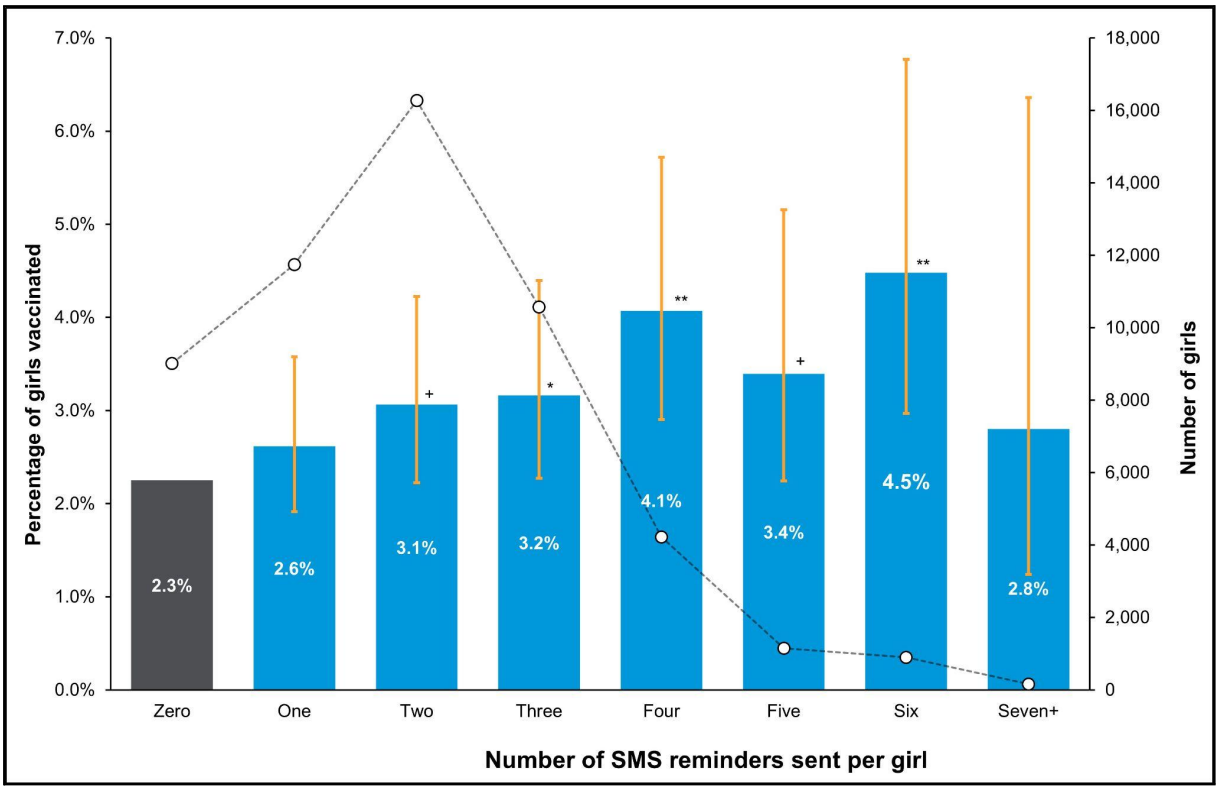
*n = 54,028 (disaggregated by age); ** p < 0.01, * p <0.05, + p <0.1; 95% CIs (orange) for treatment group bars (blue)*

Exploratory analysis: controlling for Region, Number of parents, Parent 1 Type, and number of SMS reminders sent.

Another factor for which we did not prespecify our analysis, but which appears to have had a statistically significant impact on the likelihood of a girl receiving the HPV vaccine during the trial period, is the cumulative number of SMS reminders sent to all caregivers associated with the girl within the NCDC/ITA database. Although the mean number of caregivers associated with a girl was 1.8, this ranged from 1 for some girls to a maximum of 4 for others (e.g. if grandparents were listed alongside two biological parents, within the database). In addition to this, within the database, each caregiver could have up to six telephone contact numbers associated with them. In reality, most caregivers had only one or two contact numbers associated with them within the database, and so the maximum number of SMS reminders sent to the caregivers of an individual girl was 10, with the mean number of individual SMS messages sent to the caregiver(s) of a girl being 1.9. For instance, in the case of the girl whose caregivers cumulatively received 10 SMS messages (all of SMS reminder version 4), the girl had 3 caregivers listed within the database, and these caregivers had 4, 3, and 3

valid contact numbers respectively. As randomisation was carried out at the girl level, messages sent to the caregiver(s) of a girl were all identical (unless they had eligible girls in different treatment arms in their care, with such 'spillover' addressed below).

Figure 4: Vaccination rate (primary axis, LHS) and number of girls (secondary axis, RHS) disaggregated by number of SMS reminders sent per girl



*n = 54,028; ** p < 0.01, * p <0.05, + p <0.1; 95% CIs (orange) included for bars representing non-zero numbers (blue)*

Exploratory analysis: controlling trial (control/treatment) arm, Region, # of parents, and Parent 1 Type.

Controlling for all other factors, for *each* additional SMS message a girl's caregiver(s) were sent, the girl was on average 10% *more* likely to have received the HPV vaccine within the trial period (odds ratio = 1.10 [SE = 0.02; 95% CI = (1.06, 1.14)]) . It is notable that this result controls for the number of caregivers associated with a given girl within the NCDC data, and that the raw number of caregivers itself is not found to have a statistically significant effect on the likelihood of vaccination (odds ratio of 1.09 [SE 0.07; 95% CI = (0.96, 1.24)]). Therefore the 10% effect being reported here is purely a reflection of the number of unique caregiver phone numbers registered with the NCDC that are associated with the girl, and is compatible with two explanations. Firstly, it is possible that the impact of the treatment - a girl's

caregiver(s) being sent SMS reminder(s) - on the likelihood of the girl receiving the vaccine simply grows (in cumulative terms and by an average of 10% per SMS) with the number of SMS reminders sent. If this is the case, it is an important secondary result, as it highlights the importance of keeping accurate caregiver contact details within the e-health system, and of contacting as many caregivers as possible with such reminders or informational messages. However, a competing (or complementary) explanation that must be considered is that caregivers/families who register a greater number of contact numbers with the NCDC (via family doctors, etc.) are inherently more likely to bring their daughter(s) to be vaccinated upon receiving an SMS reminder - i.e. they may have a greater *latent* desire for their daughter to be vaccinated, and/or a greater trust in the health system generally, but had not yet organised HPV vaccination for their daughter(s).

Ideally, we could use some other information to corroborate or contradict this second explanation in particular, for instance qualitative data on caregivers' attitudes towards vaccination and the public health system, and/or data on each girl's uptake of other vaccines or on her and her family's engagement with the public health system generally. However, in the absence of such data we must simply state that a girl's caregivers being sent additional SMS reminders, via a greater number of registered contact numbers registered with the NCDC, was associated with a greater likelihood of the girl receiving the HPV vaccine during the trial period. Whether or not this is driven by a greater latent desire among caregivers for their daughters to receive the vaccine, and/or by a greater trust in the health system generally, the result demonstrates the importance of importance of keeping accurate caregiver contact details within the e-health system, and of contacting as many caregivers as possible with such reminders or informational messages.

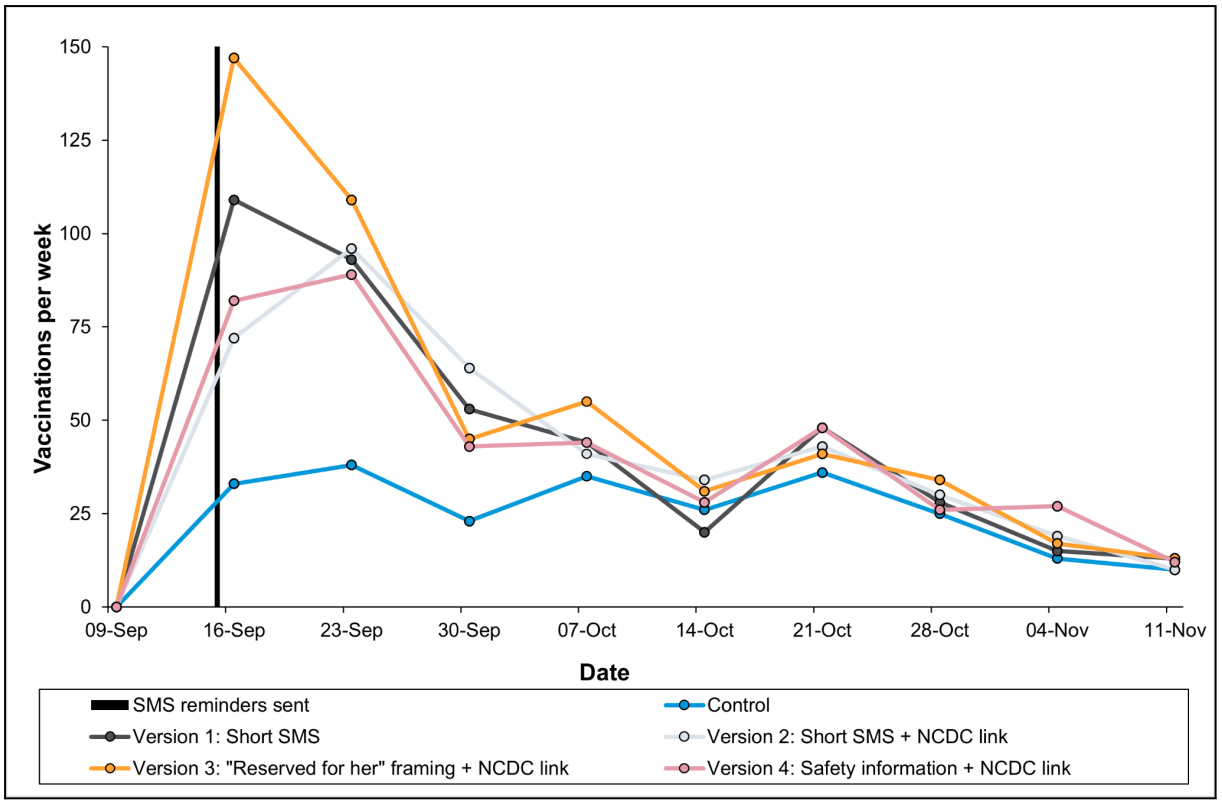
3.5 Trends in vaccination during trial period

One final piece of analysis we performed was to map out the vaccinations over time, and by trial arm, to give a visual representation of the impact of the intervention. Figure 5 shows the number of vaccinations *per week* for each of the five trial arms (control and four treatment arms) from the week beginning 09/09/22 (6 days before the SMS reminders were sent on 15/09/22) to the week beginning 11/11/22 (in which the data was collected). As with all other analysis described above, we exclude girls who had in fact received the HPV vaccine before the trail began, but were erroneously included in the original dataset (see '*Data Cleaning*' within the Materials and Methods section below for an explanation of their presence, how this was balanced across trial arms, and how they were not included in the analysis). Therefore

by definition the number of vaccinations in the week commencing 09/09/22 was zero for each trial arm. The SMS reminders were all sent on 15/09/22, and they appear to have had an immediate effect on vaccination across all treatment arms, relative to the control. Although the number of vaccinations in subsequent weeks gradually declined, the rate of vaccination in the treatment groups generally remained elevated above that of the control group until the end of the trial.

There are two further observations of note from Figure 5, the first of which is the distinctively high number of vaccinations among the group that received the "*reserved for her*" SMS (orange graphline) that occurred in the weeks immediately following the intervention. It is possible that this "*reserved for her*" framing prompted a more immediate call to action from recipient caregivers, relative to those who received version 2 and 4 of the SMS reminder, for instance. The second phenomenon of note is that there is no obvious indication of some spillover effect visible in the (blue) graphline of the control group. As noted in '*Spillover*' within the Materials and Methods section below, 1,871 (17.0%) of girls in the control group had at least one caregiver who was sent an SMS reminder in error, and caregivers of girls in the control group may have learned of the SMS through conversing with caregivers who was sent an SMS reminder. Whether this is evident or detectable from the graph lines in Figure 5 or not, it is worth remembering that while any spillover is undesirable from the perspective of analysis, it would ultimately lead to an underestimation of the effects of the intervention (rather than an overestimation), and likely a higher number of girls receiving potentially life-saving vaccine.

Figure 5: Vaccinations per week, by trial arm



N.B. Dates in the graph mark the start of each week (i.e. "09-Sep" refers to the week commencing 09/09/22). Figures for the final 'week' (beginning 11-Nov) are artificially deflated due to the fact that the dataset includes data up to and including 16th November only.

4. Discussion

4.1 Primary analysis

The results outlined above show a positive and statistically significant impact for each of the four versions of the SMS reminder, relative to the control condition where no SMS reminder was sent. While each of the four versions of the SMS achieved a statistically significant increase in vaccination relative to the control group, version 3 of the SMS reminder (with "*reserved for her*" framing) was the most effective in encouraging uptake of the HPV vaccine. This corroborates what is found in the literature in other contexts [15,16]. If all caregivers in the trial had received this most effective message, we estimate that an additional 488 girls would have been vaccinated, in addition to the 2,032 that received the HPV vaccine during the trial. In short, cumulatively the four versions of our SMS reminder intervention were associated with a 75% relative increase in vaccination rate compared to the control (no SMS), at a marginal cost of just $0.15 (0.40 GEL at the time of writing) per additional

vaccination observed. This result was obtained targeting only one of the barriers to vaccination (a lack of reminders for caregivers) identified in the previous phase of the project, and with a sample of girls whose caregivers had not yet brought them to receive the HPV vaccine. It is probable that these caregivers were more hesitant towards the HPV vaccine than the average caregiver in Georgia. Furthermore, the results and effect size presented in this report as part of the ITT analysis are potentially understated due to spillover of the treatment into 17% of the control group.

4.2 Challenges in implementation

While the intervention was implemented with relative ease, there are still some lessons to note for future implementation in similar contexts. These lessons are primarily concerned with the spillover that occurred when 17.0% of girls in the control group had at least one caregiver who was sent at least one version of the SMS reminders intended solely for the treatment groups. Upon reflection it may have been advisable to further explore the possibility of randomising at the level of the caregiver, rather than at the level of the girl. While in practice this may prove challenging given the availability of all necessary data, and may complicate data analysis somewhat, it would ensure for example that two sisters who have both been included in such a trial receive the same treatment or non-treatment by design, rather than by unintended spillover. Thankfully in this instance, it has not significantly impacted the validity or strength of the results. It is worth noting that if anything this effective spillover has likely led to an *underestimation* of treatment effects within the ITT analysis.

A further consideration when planning to implement such an intervention in similar contexts, is the requirement for a centralised or single digital database containing the requisite data on vaccination status, demographics, and contact details. While this was possible due to the ultimate availability of this data via the NCDC and ITA, it may not be possible in all low- or middle-income countries, where necessary elements (such as digitalisation of health records) may be lacking.

4.3 Implications and conclusion

The results of this trial represent a novel contribution to the literature given they represent the application of an emerging tool (SMS reminders informed by behavioural science) to a new context where it had not previously been tested. Working directly with partners in the NCDC and ITA, we were able to achieve extraordinary scale with over 55,000 girls aged 10-12

included in our trial, representing the entire population of eligible unvaccinated girls of this age, and allowing us to have five well-powered trial arms testing four versions of the SMS reminder. Ultimately the 65% effect size (observed by comparing the vaccination rate of the control group with that of the "*reserved for her*" treatment group) compares favourably to the 28% anticipated effect size suggested in the academic literature [25]. This is a notable result for what was in essence a recall campaign, for girls that were already eligible for the HPV vaccine and whose caregivers were simply receiving a reminder of this (i.e. rather than a scheduled notification upon becoming eligible for vaccination). Therefore it is likely that the population of girls included within our trial are those with caregivers who either through complacency, a lack of understanding, or hesitancy, had not taken their daughters to receive the HPV vaccine before the trial.

If all of the sample of 55,176 girls in the trial had been sent the "reserved for her" SMS reminder (version 3), this would have resulted in approximately 2,520 girls receiving the HPV vaccine during the 62-day period, meaning a further 488 girls aged 10-12 receiving the vaccine in just 62 days. If we compare a scenario in which all girls in the sample had caregivers who were sent the "reserved for her framing" SMS (version 3) against a scenario where no SMS reminders were sent, the difference would have been an additional 1,250 girls receiving the vaccine (i.e. 2,565 girls if all received version 3; vs 1,315 girls if no SMS reminders were sent). The total cost of sending 97,057 SMS reminders across all treatment arms was approximately $146 (USD), a marginal cost of less than $0.01 per SMS sent. Given that the cost of sending SMS reminders to each treatment arm was $36.50, and that version 3 of the SMS achieved 250 vaccinations in excess of the control group, we estimate a marginal cost of less than $0.15 for each additional vaccination attributable to version 3 of the SMS reminder. Note that these calculations of marginal cost assume the prior existence of an e-health system for sending such SMS reminders, as is the case in Georgia. Establishing such a system from scratch could add significant implementation costs if this trial was to be replicated in other contexts where this would be required.

The results of this trial show great promise for achieving considerable real-world impact at a low cost, and already the NCDC and Ministry of Health in Georgia have decided to 1) use the most effective version of the SMS ("*reserved for her*" framing) with all future cohorts of 10-12 year old girls as they become newly eligible for vaccination, and 2) scale the use of this version of the SMS to their national catch-up campaign for unvaccinated 13-18 year olds, potentially leading to thousands of HPV vaccinations that may not have occurred otherwise.

Furthermore, these national health authorities have decided to expand the use of this "*reserved for her*" framing to their 2023 public health reminder campaigns for routine immunisation, screening for breast cancer, cervical cancer, colorectal cancer, and screening for hepatitis C - demonstrating the immediate and far-reaching impact of this trial. Ultimately the SMS reminder intervention evaluated in this trial directly addresses only one (a lack of reminders for caregivers) of the many barriers to vaccination present in Georgia, and likely present in other contexts also. While the SMS reminders have demonstrated promising potential, it will also be necessary for public health authorities and policymakers to implement - and evaluate - interventions and policies that target other barriers to children receiving this and other potentially life-saving vaccines.

Data and code availability

A fully anonymised copy of NCDC/ITA data used in the analysis, and accompanying Stata 16.0 code, is available from the corresponding author upon reasonable request.

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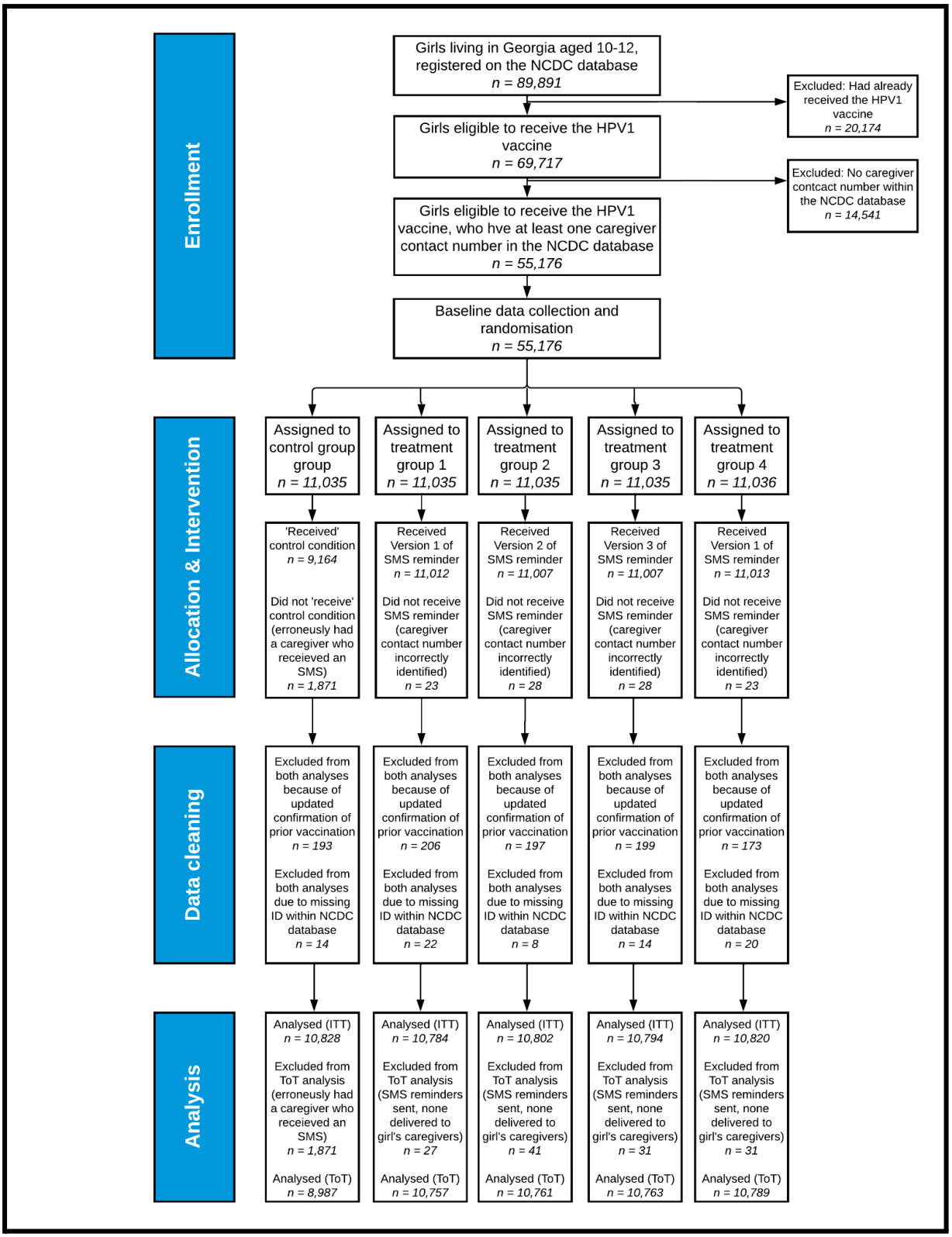
Appendix

Appendix A: Participant flow and exclusion diagram

Figure A1: Participant flow and exclusion diagram for enrollment, allocation, and analysis



Appendix B: Results of logistic regression models of predictors of HPV vaccination

Table B1: Logistic Regression results for full valid sample; ITT and ToT.

VARIABLES	(1) Intention-to-treat (ITT)	(2) Treatment-on-treated (ToT)
SMS version 1	0.349*** (0.092)	0.368*** (0.101)
SMS version 2	0.295*** (0.092)	0.317*** (0.102)
SMS version 3	0.500*** (0.090)	0.521*** (0.010)
SMS version 4	0.299*** (0.092)	0.320*** (0.102)
Age	-0.339*** (0.033)	-0.355*** (0.033)
Number of parents	0.089 (0.065)	0.092 (0.066)
Number of SMS reminders sent	0.096*** (0.020)	0.093*** (0.021)
Region: Adjara	0.676*** (0.072)	0.682*** (0.073)
Region: Guria	0.847*** (0.130)	0.857*** (0.132)
Region: Imereti	0.095 (0.078)	0.111 (0.079)
Region: Kakheti	0.544*** (0.104)	0.545*** (0.105)
Region: Kvemo Kartli	0.006 (0.084)	0.015 (0.085)
Region: Mtskheta-Mtianeti	-0.445* (0.264)	-0.419 (0.264)
Region: Racha-Lechkhumi and Kemo-Svaneti	-0.377 (0.587)	-0.362 (0.587)
Region: Samegrelo and Zemo-Svaneti	0.182* (0.100)	0.176* (0.102)
Region: Samtskhe-Javakheti	-0.091 (0.169)	-0.059 (0.170)
Region: Shida Kartli	-0.913*** (0.149)	-0.927*** (0.152)
Region: Unknown	0.012 (0.088)	0.016 (0.089)
Parent 1 Type: Custodian Organisation	0.058 (0.253)	0.154 (0.261)
Parent 1 Type: Father	-0.111** (0.049)	-0.112** (0.049)
Parent 1 Type: Guardian	-0.472 (0.309)	-0.407 (0.310)
Parent 1 Type: Unknown	0.036 (0.204)	0.024 (0.207)
Constant	-0.341 (0.403)	-0.189 (0.412)
Pseudo R^2	0.030	0.031
Observations	54,028	52,057

*Notes: Standard errors in parentheses [*** p<0.01, ** p<0.05, * p<0.1]. Results for covariates are presented as raw logit coefficients, such that [Odds Ratio = exp(coefficient)]. The dependent variable (receiving the HPV vaccine) is coded such that 0 = did not receive the vaccine, and 1 = received the vaccine. Coefficients for the SMS versions are with reference to the Control; coefficients for the regions are with reference to the Tbilisi region; coefficients for Parent 1 type variables are with reference to Parent 1 type as Mother.*

Table B2: Logistic Regression results for full valid sample; ITT disaggregated by Age groups.

VARIABLES	(1) Age 10 only	(2) Age 11 only	(3) Age 12 only
SMS version 1	0.243** (0.123)	0.684*** (0.183)	0.198 (0.217)
SMS version 2	0.281** (0.123)	0.412** (0.187)	0.200 (0.217)
SMS version 3	0.467*** (0.120)	0.678*** (0.182)	0.368* (0.212)
SMS version 4	0.252** (0.123)	0.460** (0.186)	0.256 (0.215)
Number of parents	0.401** (0.198)	-0.014 (0.101)	0.076 (0.112)
Number of SMS reminders sent	0.080*** (0.026)	0.129*** (0.039)	0.120** (0.051)
Region: Adjara	0.819*** (0.096)	0.599*** (0.134)	0.330* (0.191)
Region: Guria	1.249*** (0.157)	0.161 (0.304)	0.857*** (0.132)
Region: Imereti	0.249** (0.100)	-0.237 (0.165)	0.053 (0.204)
Region: Kakheti	0.621*** (0.134)	0.431** (0.200)	0525** (0.257)
Region: Kvemo Kartli	0.084 (0.117)	-0.125 (0.159)	0.004 (0.191)
Region: Mtskheta-Mtianeti	-0.235 (0.343)	-0.841 (0.586)	-0.546 (0.589)
Region: Racha-Lechkhumi and Kemo-Svaneti	-0.226 (0.722)	-	0.786 (1.029)
Region: Samegrelo and Zemo-Svaneti	0.300** (0.133)	0.072* (0.192)	-0.012 (0.102)
Region: Samtskhe-Javakheti	-0.151 (0.240)	-0.058 (0.302)	0.060 (0.394)
Region: Shida Kartli	-1.001*** (0.221)	-1.455*** (0.342)	-0.296 (0.254)
Region: Unknown	0.105 (0.106)	-0.149 (0.192)	-0.019 (0.318)
Parent 1 Type: Custodian Organisation	-	0.204 (0.353)	-0.085 (0.378)
Parent 1 Type: Father	-0.052 (0.061)	-0.174* (0.099)	-0.266* (0.140)
Parent 1 Type: Guardian	0.622 (0.607)	-0.425 (0.460)	-1.070* (0.586)
Parent 1 Type: Unknown	-0.225 (0.313)	0.450 (0.319)	0.209 (0.533)
Constant	-4.350*** (0.398)	-4.073*** (0.223)	-4.178*** (0.235)
Pseudo R^2	0.026	0.028	0.012
Observations	23,711	17,074	13,171

*Notes: Standard errors in parentheses [*** p<0.01, ** p<0.05, * p<0.1]. Results for covariates are presented as raw logit coefficients, such that [Odds Ratio = exp(coefficient)]. The dependent variable (receiving the HPV vaccine) is coded such that 0 = did not receive the vaccine, and 1 = received the vaccine. Coefficients for the SMS versions are with reference to the Control; coefficients for the regions are with reference to the Tbilisi region; coefficients for Parent 1 type variables are with reference to Parent 1 type as Mother.*

Table B3: Logistic Regression results for full valid sample; ITT disaggregated by count of SMS sent per girl.

VARIABLES	(1) Intention-to-treat (ITT)
SMS version 1	0.276*
	(0.152)
SMS version 2	0.222
	(0.153)
SMS version 3	0.425***
	(0.151)
SMS version 4	0.224
	(0.153)
Age	-0.338***
	(0.033)
Number of parents	0.085
	(0.067)
Region: Adjara	0.675***
	(0.072)
Region: Guria	0.842***
	(0.130)
Region: Imereti	0.094
	(0.078)
Region: Kakheti	0.547***
	(0.104)
Region: Kvemo Kartli	0.005
	(0.084)
Region: Mtskheta-Mtianeti	-0.444*
	(0.264)
Region: Racha-Lechkhumi and Kemo-Svaneti	-0.366
	(0.587)
Region: Samegrelo and Zemo-Svaneti	0.178*
	(0.101)
Region: Samtskhe-Javakheti	-0.092
	(0.169)
Region: Shida Kartli	-0.913***
	(0.149)
Region: Unknown	0.013
	(0.088)
Parent 1 Type: Custodian Organisation	0.060
	(0.254)
Parent 1 Type: Father	-0.112**
	(0.049)
Parent 1 Type: Guardian	-0.478
	(0.309)
Parent 1 Type: Unknown	0.048
	(0.205)
One SMS reminder sent	0.149
	(0.161)
Two SMS reminders sent	0.307*
	(0.165)
Three SMS reminders sent	0.340***
	(0.169)
Four SMS reminders sent	0.592***
	(0.175)
Five SMS reminders sent	0.410*
	(0.215)

Six SMS reminders sent	0.688*** (0.212)
Seven or more SMS reminders sent	0.218 (0.421)
Constant	-0.357 (0.404)
Pseudo R^2	0.030
Observations	54,028

*Notes: Standard errors in parentheses [*** p<0.01, ** p<0.05, * p<0.1]. Results for covariates are presented as raw logit coefficients, such that [Odds Ratio = exp(coefficient)]. The dependent variable (receiving the HPV vaccine) is coded such that 0 = did not receive the vaccine, and 1 = received the vaccine. Coefficients for the SMS versions are with reference to the Control; coefficients for the regions are with reference to the Tbilisi region; coefficients for Parent 1 type variables are with reference to Parent 1 type as Mother; coefficients for the number of SMS sent per girl are with reference to girls for whom no SMS (zero) was sent.*

Appendix C: Balance checks post-randomisation (pre-cleaning)

Table C1: Balance checks showing an consistent distribution by region, across trial arms

Region / Treatment Group	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	Control	*Full sample*
Adjara	919 (8.4%)	981 (8.9%)	948 (8.6%)	1,009 (9.1%)	876 (7.9%)	***4,733 (8.6%)***
Guria	210 (1.9%)	181 (1.6%)	192 (1.7%)	175 (1.6%)	182 (1.6%)	***940 (1.7%)***
Imereti	1,141 (10.3%)	1,233 (11.2%)	1,122 (10.2%)	1,225 (11.1%)	1,219 (11.0%)	***5,940 (10.8%)***
Kakheti	420 (3.8%)	419 (3.8%)	420 (3.8%)	400 (3.6%)	434 (3.9%)	***2,093 (3.8%)***
Kvemo Kartli	1,134 (10.3%)	1,123 10.2%)	1,116 (10.1%)	1,102 (10.0%)	1,112 (10.1%)	***5,587 (10.1%)***
Mtskheta-Mtianeti	134 (1.2%)	132 (1.2%)	157 (1.4%)	140 (1.3%)	145 (1.3%)	***708 (1.3%)***
Racha-Lechkhumi and Kvemo Svaneti	27 (0.2%)	24 (0.2%)	36 (0.3%)	16 (0.1%)	22 (0.2%)	***125 (0.2%)***
Samegrelo and Zemo Svaneti	614 (5.6%)	610 (5.5%)	608 (5.5%)	573 (5.2%)	639 (5.8%)	***3,044 (5.5%)***
Samtskhe-Javakheti	260 (2.4%)	248 (2.2%)	236 (2.1%)	272 (2.5%)	261 (2.4%)	***1,277 (2.3%)***
Shida Kartli	748 (6.8%)	713 (6.5%)	726 (6.6%)	747 (6.8%)	744 (6.7%)	***3,678 (6.7%)***
Tbilisi	4,491 (40.7%)	4,493 (40.7%)	4,610 (41.8%)	4,523 (41.0%)	4,491 (40.7%)	***22,608 (41.0%)***
(Unknown, no data)	937 (8.5%)	878 (8.0%)	864 (7.8%)	854 (7.7%)	910 (8.2%)	***4,443 (8.1%)***
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	**11,035 (100%)**	***55,176 (100%)***

Table C2: Balance checks showing an consistent distribution by age, across trial arms

Age / Treatment Group	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	Control	*Full sample*
10	4,912 (44.5%)	4,855 (44.0%)	4,919 (44.6%)	4,808 (43.6%)	4,963 (45.0%)	***24,457 (44.3%)***
11	3,422 (31.0%)	3,479 (31.5%)	3,460 (31.4%)	3,535 (32.0%)	3,438 (31.2%)	***17,334 (34.4%)***
12	2,701 (24.5%)	2,701 (24.5%)	2,656 (24.1%)	2,693 (24.4%)	2,634 (23.9%)	***13,385 (24.3%)***
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	**11,035 (100%)**	***55,176 (100%)***

Table C3: Balance checks showing a consistent distribution across trial arms, by number of parents

Parent Count / Treatment Group	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	Control	*Full sample*
1	2,473 (22.4%)	2,466 (22.3%)	2,476 (22.4%)	2,411 (21.8%)	2,521 (22.8%)	***12,347 (22.4%)***
2	8,249 (74.8%)	8,228 (74.6%)	8,245 (74.7%)	8,303 (75.2%)	8,225 (74.5%)	***41,250 (74.8%)***
3	312 (2.8%)	340 (3.1%)	313 (2.8%)	321 (2.9%)	287 (2.6%)	***1,573 (2.9%)***
4	1 (0.01%)	1 (0.01%)	1 (0.01%)	1 (0.01%)	2 (0.02%)	***6 (0.01%)***
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	**11,035 (100%)**	***55,176 (100%)***

Table C4: Balance checks showing an consistent distribution by number of SMS reminders sent, across treatment arms only

SMS sent count	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	*Total (Treatment groups)*
0 (error)	*23 (0.2%)*	*28 (0.3%)*	*28 (0.3%)*	*24 (0.2%)*	***103 (0.2%)***
1	2,718 (24.6%)	2,732 (24.8%)	2,719 (24.6%)	2,635 (23.9%)	***10,804 (24.5%)***
2	3,977 (36.2%)	4,059 (36.9%)	4,034 (36.7%)	4,071 (37.0%)	***16,141 (36.6%)***
3	2,701 (24.5%)	2,609 (23.7%)	2,596 (23.4%)	2,716 (24.7%)	***10,622 (24.1%)***
4	1,056 (9.5%)	1,048 (9.5%)	1,091 (9.9%)	1,022 (9.3%)	***4,217 (9.6%)***
5	300 (2.7%)	290 (2.6%)	280 (2.5%)	296 (2.7%)	***1,166 (2.6%)***
6	219 (2.0%)	219 (1.9%)	240 (2.2%)	242 (2.1%)	***920 (2.1%)***
7	35 (0.3%)	39 (0.4%)	43 (0.4%)	27 (0.2%)	***144 (0.3%)***
8	6 (0.1%)	8 (0.1%)	3 (0.0%)	1 (0.0%)	***18 (0.0%)***
9	0 (0.0%)	3 (0.0%)	1 (0.0%)	1 (0.0%)	***5 (0.0%)***
10	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.0%)	***1 (0.0%)***
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	***44,141 (100%)***

Table C5: Balance checks showing an consistent distribution by 'type' of 'Parent 1', across trial arms

Parent 1 Type / Treatment Group	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	Control	*Full sample*
Mother	6,231 (56.5%)	6,227 (56.4%)	6,352 (57.6%)	6,311 (57.2%)	6,339 (57.4%)	31,460 (57.0%)
Father	4,395 (39.8%)	4,401 (39.9%)	4,317 (39.1%)	4,329 (39.2%)	4,313 (39.1%)	21,755 (39.4%)
Guardian	151 (1.4%)	120 (1.1%)	129 (1.2%)	124 (1.1%)	132 (1.2%)	656 (1.2%)
"*Custodian organisation contact person*"	112 (1.0%)	124 (1.1%)	96 (0.9%)	113 (1.0%)	105 (1.0%)	550 (1.0%)
(Unknown, no data)	146 (1.3%)	163 (1.5%)	141 (1.3%)	159 (1.4%)	146 (1.3%)	755 (1.4%)
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	**11,035 (100%)**	***55,176 (100%)***

Table C6: Balance checks showing a consistent distribution across trial arms, for SMS metrics

SMS metric / Treatment Group	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	*Total (Treatment groups)*
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	***44,141 (100%)***
SMS sent	11,012 (99.8%)	11,007 (99.7%)	11,007 (99.7%)	11,012 (99.8%)	***44,038 (99.8%)***
SMS delivered	10,985 (99.5%)	10,966 (99.4%)	10,974 (99.4%)	10,980 (99.5%)	***43,905 (99.5%)***
SMS status delivered	10,350 (93.8%)	10,364 (93.9%)	10,348 (93.8%)	10,361 (93.9%)	***41,423 (93.8%)***

Table C7: Balance checks across trial arms for observations dropped in the data cleaning process

Cleaning issue / Treatment Group	Version 1: Short SMS	Version 2: Short SMS + NCDC link	Version 3: 'Reserved for her' framing + NCDC link	Version 4: Safety information + NCDC link	Control	***Full sample***
Total	**11,035 (100%)**	**11,035 (100%)**	**11,035 (100%)**	**11,036 (100%)**	**11,035 (100%)**	***55,176 (100%)***
Dropped due to invalid ID	22 (0.2%)	8 (0.1%)	14 (0.1%)	20 (0.2%)	14 (0.1%)	***78 (0.1%)***
Dropped due to being vaccinated before the trial	206 (1.9%)	197 (1.8%)	199 (1.8%)	174 (1.6%)	193 (1.7%)	***969 (1.8%)***
Dropped due to no SMS sent	23 (0.2%)	28 (0.3%)	28 (0.3%)	24 (0.2%)	*N/A*	***103 (0.2%)***
Cumulative number of observations dropped	***251 (2.3%)***	***233 (2.1%)***	***241 (2.2%)***	***218 (2.0%)***	***207 (1.9%)***	***1,150* (2.1%)***

** In practice, the actual total of observations dropped in the cleaning process was 1,148, 2 fewer than the figure of 1,150 presented here. This is because two observations were disqualified for two or more of the three reasons presented in this table, resulting in minor double-counting within the figure of 1,150 presented here. The number of observations in the cleaned dataset is therefore 54,028 (55,176 - 1,148).*

Appendix D: Model specification

We use the following model specification to test the effect of BI-informed SMS reminders against no reminder:

$$Y_i \sim bernoulli(p_i)\,;\; logit(p_i) = \alpha + \beta_T treatment + x_i$$

Where:

- Y_i refers to the primary outcome, i.e. whether the eligible girl has been vaccinated with the first dose of the HPV vaccine or not 62 days after the SMS reminder is sent.
- $treatment_i$ is the vector of treatment dummy indicators (0 = No reminder, 1 = relevant SMS reminder)).
- x represents the covariates, including girl's age in years (ranging from 10 to 12), region, number of parents, parent 1 'type (mother, father, guardian, etc.), and number of SMS reminders sent by the NCDC/ITA (number of accurate phone numbers associated with each girl).

We used the statistical analysis software Stata 16.1 to perform this analysis.

Appendix E: SMS reminders in English and in Georgian

Table E1: SMS reminders in English and Georgian

Version		SMS reminder message (English version)	SMS reminder message (Georgian version)
1	**Short SMS with no additional information**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. Contact your polyclinic today to arrange an appointment."*	*თქვენს გოგონას იმუნიზაციის ეროვნული კალენდრით ეკუთვნის ადამიანის პაპილომავირუსის საწინააღმდეგო გეგმიური უფასო აცრა, რომელიც მას საშვილოსნოს ყელის კიბოსაგან დაიცავს. აცრის დასაგეგმად დაუკავშირდით თქვენი ოჯახის ექიმს დღესვე.*
2	**Short SMS + NCDC link to more information**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. Contact your polyclinic today to arrange an appointment. More information on the official NCDC website: [LINK]"*	*თქვენს გოგონას იმუნიზაციის ეროვნული კალენდრით ეკუთვნის ადამიანის პაპილომავირუსის საწინააღმდეგო გეგმიური უფასო აცრა, რომელიც მას საშვილოსნოს ყელის კიბოსაგან დაიცავს. აცრის დასაგეგმად დაუკავშირდით თქვენი ოჯახის ექიმს დღესვე. დამატებითი ინფორმაცია იხილეთ დაავადებათა კონტროლის ეროვნული ცენტრის ვებგვერდზე: [ბმული„]*
3	**SMS with "*reserved for her*" framing + NCDC link**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. Her vaccine is reserved for her at the polyclinic. Contact them today to arrange an appointment. More information on the official NCDC website: [LINK]"*	*თქვენს გოგონას იმუნიზაციის ეროვნული კალენდრით ეკუთვნის ადამიანის პაპილომავირუსის საწინააღმდეგო გეგმიური უფასო აცრა, რომელიც მას საშვილოსნოს ყელის კიბოსაგან დაიცავს. მისთვის განკუთვნილი ვაქცინა დაჯავშნილია პოლიკლინიკაში. აცრის ჩასატარებლად დაუკავშირდით თქვენი ოჯახის ექიმს დღესვე. დამატებითი ინფორმაცია იხილეთ დაავადებათა კონტროლის ეროვნული ცენტრის ვებგვერდზე: [ბმული„]*
4	**SMS with safety information + NCDC link**	*"Your daughter is due her free human papillomavirus (HPV) vaccine which will protect her against cervical cancer. The vaccine has been given safely to more than 118 million girls worldwide. Contact your polyclinic today to arrange an appointment. More information on the official NCDC website: [LINK]"*	*თქვენს გოგონას იმუნიზაციის ეროვნული კალენდრით ეკუთვნის ადამიანის პაპილომავირუსის საწინააღმდეგო გეგმიური უფასო აცრა, რომელიც მას საშვილოსნოს ყელის კიბოსაგან დაიცავს. ვაქცინა უსაფრთხოა და მთელ მსოფლიოში ის უკვე 118 მილიონზე მეტ გოგონას ჩაუტარდა. აცრის დასაგეგმად დაუკავშირდით თქვენი ოჯახის ექიმს დღესვე. დამატებითი ინფორმაცია იხილეთ დაავადებათა კონტროლის ეროვნული ცენტრის ვებგვერდზე: [ბმული„]*