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Behavioral changes associated to the COVID-19 vaccination: Evidence from a cross-national online survey

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Behavioral changes associated to the COVID-19 vaccination: Evidence from a cross-national online survey

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Abstract

Background: During the initial phases of the vaccination campaign worldwide, Non-Pharmaceutical Interventions (NPIs) remained pivotal in the fight against the COVID-19 pandemic. In this context, it is important to understand how the arrival of vaccines affected the adoption of NPIs. Indeed, some individuals might have seen the start of mass vaccination campaigns as the end of the emergency and, as a result, have relaxed their COVID-safe behaviors, facilitating the spread of the virus in a delicate epidemic phase such as the initial rollout.

Objective: Our study aims to collect information about the possible relaxation of behaviors following key events of the vaccination campaign in four countries and to analyse possible associations of these behavioral tendencies with socio-demographic characteristics of participants.

Methods: We developed an online survey named “COVID-19 Prevention and Behavior Survey” that we conducted between November 26 and December 22, 2021. Participants were recruited using targeted ads on Facebook in four different countries: Italy, the United Kingdom, Brazil and South Africa. We measured the onset of relaxation of protective measures in response to key events of the vaccination campaign, namely personal vaccination and vaccination of the most vulnerable population. Through odds ratios and regression analysis we assessed the strength of association between compliance with NPIs and socio-demographic characteristics of participants.

Results: We received 2263 questionnaires from the four countries. Participants reported the most significant changes in social activities, such as going to restaurant or cinema and visiting relatives and friends. This is in good agreement with validated psychological models of health-related behavioral change such as the Health Belief Model (HBM), according to which activities with higher costs and perceived barriers (e.g., the social activities) are more prone to early relaxation. Multivariate analysis using a Generalised Linear Model showed that the two main determinants of the drop of social NPIs are i) having previously tested positive for COVID-19 (after second dose: OR 2.46, 95% CI 1.73-3.49) and ii) living with people at risk (after second dose: OR 1.57, 95% CI 1.22-2.03).

Conclusions: This work shows that particular caution has to be taken during vaccination campaigns. Indeed, people might relax their safe behaviors regardless the dynamics of the epidemic. For this reason, it is crucial to keep high the compliance with NPIs to avoid hindering the beneficial effects of the vaccine. Clinical Trial: Ethical approval: Ethical approval was obtained from the bioethical committee of the University of Turin (Prot. n. 280342 del 8.5.2021).

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Background: During the initial phases of the vaccination campaign worldwide, Non-Pharmaceutical Interventions (NPIs) remained pivotal in the fight against the COVID-19 pandemic. In this context, it is important to understand how the arrival of vaccines affected the adoption of NPIs. Indeed, some individuals might have seen the start of mass vaccination campaigns as the end of the emergency and, as a result, have relaxed their COVID-safe behaviors, facilitating the spread of the virus in a delicate epidemic phase such as the initial rollout.
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Conclusions: This work shows that particular caution has to be taken during vaccination campaigns. Indeed, people might relax their safe behaviors regardless the dynamics of the epidemic. For this reason, it is crucial to keep high the compliance with NPIs to avoid hindering the beneficial effects of the vaccine.

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Keywords: COVID-19; Vaccines; Social behaviors; Online surveys; Non pharmaceutical interventions

Introduction

The COVID-19 pandemic impacted humanity on an unprecedented scale causing, as of February 2023, over 757 million confirmed cases and over 6.8 million deaths [CITATION whoweeklyupdate \l 1033]. At the beginning of 2021, vaccination campaigns were rolled out in many countries, providing a pharmaceutical measure to protect against the most severe manifestations of the disease and to contrast the spreading of the virus. Before vaccines were made available, the mitigation of

infections and deaths was largely achieved through non-pharmaceutical interventions (NPIs) such as lockdowns, social distancing, curfews and use of protective face masks [CITATION perra2021non \l 1033]. These measures aimed at controlling the epidemic diffusion by reducing overall social contacts as well as by limiting the spreading potential of unavoidable social interactions [CITATION del2021differential \l 1033][CITATION jarvis2020quantifying \l 1033][CITATION coletti2020comix \l 1033]. A significant body of literature focused on the efficacy of these measures in reducing disease transmission across different contexts and geographies [CITATION basellini2021linking \l 1033][CITATION ge2022impacts \l 1033][CITATION vlachos2021effects \l 1033][CITATION hale2021government \l 1033] and the socio-economic disruption to everyday life brought by stringent NPIs and their unequal impact on the population [CITATION bonaccorsi2020economic \l 1033][CITATION deb2022economic \l 1033][CITATION gozzi2021estimating \l 1033][CITATION pangallo2022unequal \l 1033]. Despite the incredible milestone in the fight against SARS-CoV-2 represented by the start of vaccination campaign worldwide, due to the initial limited supply and unprecedented logistic challenges, NPIs remained essential, at least in the first phases, to sustain the incredible efforts of mass immunisation campaigns and to reach adequate vaccination coverage [CITATION galanti2021social \l 1033][CITATION gozzi2021importance \l 1033].

In this complex context, the interplay between population-level mitigation measures, individual decisions related to adoption of these measures, and vaccination remain less explored. Previous studies have focused, primarily from a mathematical modeling standpoint, on the interplay between NPIs adoption, COVID-19 spread, and vaccination campaigns [CITATION gozzi2021importance \l 1033][CITATION moore2021vaccination \l 1033][CITATION patel2021association \l 1033][CITATION yang2021despite \l 1033]. They have shown that early relaxation of COVID-safe behaviors may contribute to further avoidable infections and threaten the success of the vaccination efforts. Nonetheless, empirical evidence to support and quantify if and at which rate individuals relax their behavior in response to COVID-19 vaccination is still very limited[CITATION andersson2020anticipation \l 1033].

In this study, we tackle this limitation by studying, from a data-driven standpoint, how individual vaccination status and national rollout advancement impacted the adoption of protective behaviors such as hand washing, mask wearing and social distancing. In order to account for different national contexts, especially related to heterogeneity of vaccination campaigns' progress and to the COVID-19 epidemiological situation worldwide, we developed a cross-country survey that we administered to a random sample of anonymous individuals targeted through the Advertisement platform of Facebook in Italy, Brazil, South Africa, and United Kingdom. The use of targeted Facebook ads to collect relevant social data has become a frequent practice in Computational Social Science [CITATION grow2020addressing \l 1033][CITATION schneider2022s \l 1033]. This was particularly true during the COVID-19 pandemic, when the dissemination of epidemiological and behavioral surveys through the Facebook advertisement platform has gained significant traction. One of the earliest and most successful examples is the COVID-19 World Symptoms Survey [CITATION Kreuter \l 1033], that was deployed from March 2020 to June 2022, in partnership with University of Maryland (UMD) and Carnegie Mellon University (CMU) to collect data about COVID-19 vaccine acceptance, preventive behavior and symptoms. The many insights provided by these studies were crucial to show the value of online surveys for tracking patterns and trends in COVID outcomes in a complementary fashion with respect to official reporting [CITATION UniMarylandSurvey \l 1033][CITATION CarnegieSurvey \l 1033].

Our work falls in this line of research and aims at measuring individual behavioral changes (e.g., adoption or relaxation of protective measures) in association with different stages of the vaccination campaign. In particular, we asked about the compliance with NPIs related to six different activities after key events of the vaccination campaign, such as the vaccination of the elderly and people at risk and the personal inoculation of the first dose and the second dose. By studying the over 2000

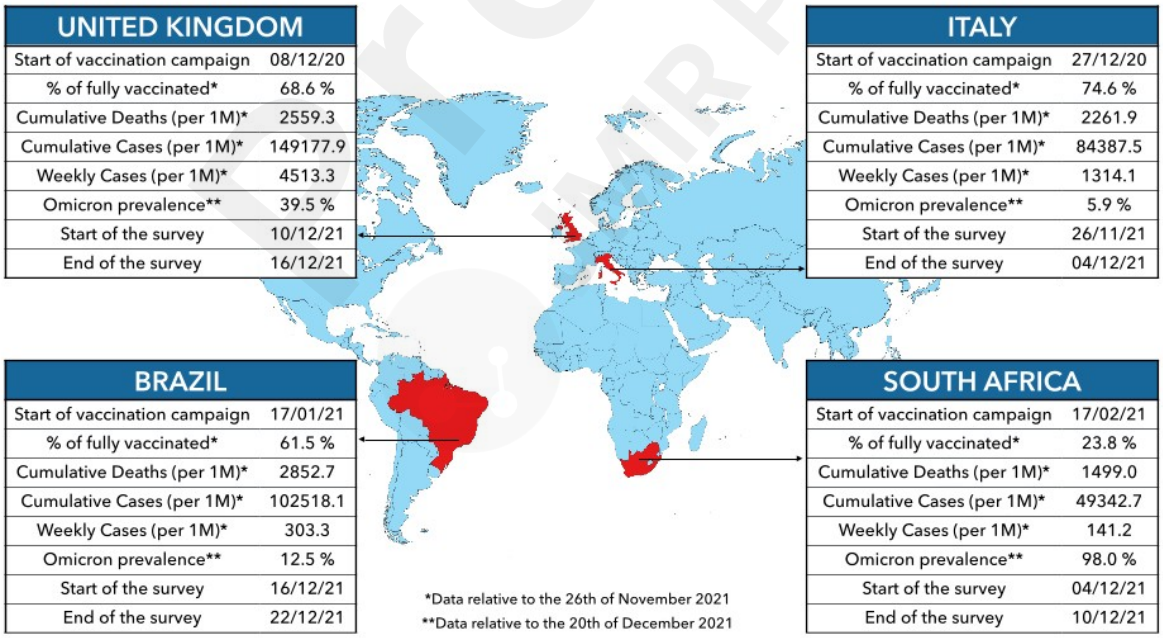
responses received, we identified that NPIs related to social activities were the ones that were relaxed the most after key stages of the vaccination campaign. This is in good agreement with the constructs of psychological theoretical frameworks such as the Health Belief Model (HBM), which suggests that NPIs with the higher associated costs are more difficult to adopt and thus are generally the first to be relaxed. From this standpoint, we performed a multivariate analysis using a Generalized Linear Model in order to quantify the association between the relaxation of social activities and socio-demographic characteristics, such as country of residence, age group and sex. Results show that the 2 most important determinants of the relaxation of social behaviors are having tested positive to COVID-19 and living with people at risk.

Methods

Our survey study was conducted during late November/December 2021. As of December 1st, 2021, Italy and UK had respectively 75% and 69% of individuals that completed the initial COVID-19 vaccination protocol. Vaccination uptake was slightly lower in Brazil (62%), while only 24% of people were fully vaccinated in South Africa (Source: [CITATION owidcoronavirus \l 1033]). Also, in December 2021 a new and more transmissible SARS-CoV-2 variant of concern (VOC) emerged: B.1.1.529 (Omicron). In mid-December 2021, Omicron was mostly dominant in South Africa (95% of sequenced genomes), a steep increase in the number of cases was observed in UK (39%) due to this VOC, while in Brazil and Italy Omicron prevalence was still much lower (12% and 5% respectively) but quickly increasing. In Figure 1 we report these informations together with other epidemiological indicators (e.g., cumulative number of COVID-19 cases) in the surveyed countries.

Study Design

Figure 1. Informative data about each country included in the study (Source: [CITATION owidcoronavirus \l 1033]) with the dates of the beginning of the advertising campaigns.



The questionnaire "COVID-19 Vaccines and Behaviors Survey" that we developed consists of 2 sections. The first aims at collecting socio-demographic features, such as sex and age. The second focuses on understanding to which extent individuals changed behaviors in response to the COVID-19 vaccine rollout and which behaviors they relaxed, if any. We consider three different pivotal

stages of the vaccination campaign that may have acted as a trigger for the behavior change of individuals, namely the vaccination of those at higher risk of severe symptoms following COVID-19 infection (65+ and people with co-morbidities), the start of individual vaccination cycle (i.e., the first dose), and the end of individual vaccination cycle (i.e., the second dose). Indeed, since the outcome of COVID-19 infections strongly depends on age and on medical condition, people may decide to drop COVID-safe behaviors once the population at higher risk has been immunised. Similarly, individuals may feel reassured by personal (partial and full) immunisation and adapt their behaviors accordingly. We conducted our survey study in 4 countries that we selected based on different characteristics in the vaccination coverage, disease prevalence, and dominant SARS-CoV-2 strain: Italy, the United Kingdom, South Africa and Brazil. The master version of the survey was created in English and then translated, with the help of native speakers, in Italian and Portuguese. The survey was implemented via Limesurvey [CITATION limesurvey \l 1033], a web app that allows to easily deploy surveys at a scale. The English version of the survey is provided as supplementary material.

In order to recruit participants, we distributed the survey via targeted Facebook advertisements created using the Facebook Ads Manager (FAM) **[CITATION fbadsmanger \l 1033]**. We followed the methodology illustrated in Ref. **[CITATION potzschke2017migrant \l 1033]**, and more recently in Ref. **[CITATION perrotta2021behaviours \l 1033]**. We created a separate advertising campaign for each country. Each campaign contained one Ads set for each combination of the three targeting variables used to stratify the population: sex (male, female), age (18-24, 25-44, 45-64, 65+), and region of residence (based on statistical division of each country, a complete list of the macro-regions used is reported in Supplementary Information). These are well-known confounding variables and, through the stratification of Ads delivery, we were able to obtain enough responses in each stratum. Following this approach, we obtained 32 strata for South Africa and 40 for Italy, UK and Brazil. Each of them contained 6 Ads that differed only in the Ad image used. Differently from what described in Ref. **[CITATION potzschke2017migrant \l 1033]**, Facebook no longer allows more than 250 active Ads at the same time. For this reason, we launched the advertising campaign for each country separately, starting with Italy on November 26th, 2021 and ending with Brazil on December 22th, 2021 as shown in Figure 1. More details on the survey methodology are reported in Supplementary Information 1.

Inclusion criteria

We collected a total of 2263 responses: 435 from Italy (19.2% of total), 386 from UK (17.1%), 305 from Brazil (13.5%), 1014 from South Africa (44.8%), and 123 (5.4%) submitted from other countries or with no answers (that we discarded). We included in our analysis only questionnaires containing information about sex, age, and region of residence, as we need these features to correct for non-representativeness of the sample. This leads to the exclusion of an additional 196 questionnaires (8.66% of the total). In the multivariate analysis presented below we use additional features, namely education attainment, household composition, vaccination status, previous positivity to SARS-CoV- 2 and presence of risk factors for COVID-19. Therefore, for this analysis we excluded questionnaires in which these features were missing (22% of the total).
After the exclusion of non-eligible respondents, we applied post-stratification weights to align our samples with the general population of the countries considered. We stratified our respondents by sex, age and region and we calculated the percentage of respondents sp_k in each stratum k. Then, we

computed the actual percentage of population in each stratum rp_k. We used data from World Population Prospects [CITATION worldpop \l 1033], which provides estimates of the population in each country in 2020, divided by sex and 5 years age-groups. This subdivision of age groups does not allow for direct comparison with survey counts for the 18-24 age group. To address this problem, we summed the actual population in age group 20-24 with 2/5 of the population stated for age group 15-19. Finally, we computed the post-stratification weight for each stratum as the ratio between the two percentages: rp_k / sp_k.

Measuring behavioral changes

As a proxy for reduced adoption of COVID-safe behaviors, we considered the following six possible changes in activities: (i) using public transport more frequently, (ii) engaging in social activities more frequently (e.g., going to restaurants), (iii) visiting relatives and friends more frequently, (iv) reducing hygiene measures (e.g., wash hands less often, use disinfectant gel less often), (v) wearing a face mask less often (where not mandatory), and (vi) reducing the recommended physical distance (1 or 2 meters) from other people. We chose these activities as representatives of the main NPIs that were widely implemented to contrast the spread of SARS-CoV-2 before the arrival of vaccines. Specifically, survey respondents were asked if they felt more comfortable doing these activities after each of the three trigger stages of the vaccination campaign mentioned above. Possible answers to these questions were organised using a 5-point Likert scale (1 = Definitely not, 2 = No, 3 = Neither yes nor no, 4 = Yes, and 5 = Definitely yes). Participants were also given the opportunity to report “Not applicable” as an answer. These cases were treated as missing values.

For each activity we transformed responses into a binary variable defining whether an individual engaged or not in behavior change related to that activity. In particular, options 4 (Yes) or 5 (Definitely Yes) were associated to a change in behavior, while options 1 (Definitely No), 2 (No) and 3 (Neither yes nor no) were associated with no change.

We have also investigated a hypothetical scenario in which we asked respondents what would be their behavioral reaction in case of a future worsening of epidemiological conditions. In this case, we considered four measures they could adopt: (i) wear a face mask more frequently (where not mandatory), (ii) reduce social contacts, (iii) keep a higher physical distance from other people, and (iv) avoid crowded places. Also in this case, responses were given on a 5-point Likert scale (from 1 = Very unlikely to adopt, to 5 = Very likely to adopt), and we considered that the single NPI would be adopted with response options 4 (Likely) or 5 (Very likely) and not adopted with response options 1 (Very unlikely), 2 (Unlikely), 3 (Neutral). Again, “Not applicable” answers were treated as missing values.

Multivariate analysis

We also investigated how the relaxation of NPIs related to social behaviors was associated with respondents’ social and demographic characteristics. We focused on social activities since, according to the Health Belief Model framework, they are generally perceived as more costly to give up and, thus, relaxation of NPIs in these settings is more likely to occur. The Health Belief Model (HBM) is a well-known social and psychological model regarding the adoption of health-related behaviors [CITATION rosenstock1974health \l 1033][CITATION hochbaum1958public \l 1033][CITATION hayden2022introduction \l 1033]. HBM posit that the risk perception of an individual plays a pivotal role in the adoption of health behaviors. More in detail, two constructs contribute to the individual perceived threat: individuals’ belief on how likely they are to contract the disease (perceived susceptibility) and personal evaluation of the severity of the consequences of the disease (perceived severity). The perceived threat can lead to the adoption (or the relaxation) of a health-related behavior. Additionally, individuals ground their choices also on perceived benefits and perceived barriers. Perceived benefits associated with a health behavior are the personal opinions on the value

or usefulness of that behavior in reducing the perceived threat. On the other hand, perceived barriers are the individual's perception of the obstacles of adopting the new behavior. This implies that, for example, health-related behaviors with high perceived benefits may not be adopted because of their high perceived barriers. As result, health behaviors with high perceived barriers are usually the first ones to be relaxed. NPIs regarding social activities, despite having high impact on reducing the spread of the disease, are associated a high perceived cost as they prevent individuals from participating in everyday activities and from interacting with their families or friends. For this reason, of the six activities included in our questionnaire, in this part of the analysis we focused our attention only on "Engage in social activities more frequently (e.g. going to restaurants)" and "Visit relatives and friends more frequently", which onward will be referred as social activities. For the multivariate analysis we used a fixed effect model with a logistic regression and a binary outcome of 1 if at least one social activity was changed and 0 otherwise. In order to consider post-stratification weights in the regression, we opted for the Generalized Linear Model (GLM) available in the Python library statsmodels [CITATION seabold2010statsmodels \l 1033]. We used a logit function and a binomial function for outcome. In this way the GLM is effectively a logistic regression with weights. We chose logistic regression because of its explainability of the coefficients. Nonetheless, we tested also other models, for more details see Supplementary 1. The features included in the model are reported in Table 1 with reference values highlighted in bold. Moreover, we transformed each categorical feature in a set of dummy variables, using the most frequent as a reference. For example, the feature Age which can take the values 18-24, 25-44, 45-64, and 65+, was encoded into 3 dummy variables (Age 18-24, Age 25-44, Age 45-64), considering the age group 65+ as the reference. For robustness analysis on the features, see Supplementary 1.
The model is ruled by the following equation:

$$\log \frac{P(y|X)}{1-P(y|X)} = \log(odds) = \beta_0 + \sum_{k=1}^{N} \beta_k X_k$$

where $P(y|\boldsymbol{X})$ is the conditional probability of the binary outcome (y) given the set of features (X), β_0 is the intercept of the model and β_k are the coefficient related to each feature X_k. If we consider, for example, X_1 to be the binary variable Age_18 − 24, then the coefficient β_1 is the logarithm of the odds ratio comparing age group 18-24 with the reference group 65+. The odds ratio is often used in epidemiology to assess the strength of an association between an outcome and an exposure. In particular, it represents the ratio between the odds of the outcome in presence of the exposure and the odds of the outcome in absence of the exposure. Following the example above, the exponential of β_1 is the ratio of the odds of changing social behaviors (i.e., the outcome) if in the age group 18-24 (i.e., the exposure) divided by the odds of changing social behaviors if in the age group 65+ (i.e., the value taken as a reference). Therefore, by doing the exponential of the coefficients obtained from the multivariate analysis we obtain immediately a measure of the association between the variable we are considering and the change in social behavior.
The analysis was performed for all the three stages of the vaccination campaign considered in this study: vaccination of over 65 years old and people with comorbidities (i.e., the groups at risk), personal first dose and second dose. While the survey question related to the first event was accessible to all respondents, the questions related to the first and second dose were only available to vaccinated people. Nonetheless, these are almost 80% of the respondents, therefore the sample is mostly the same.
For the scenario related to a worsening of the epidemiological conditions, we performed a similar analysis. We included the same features but in this case the binary outcome is 1 if all 4 NPIs would be readopted, and 0 otherwise.

Table 1. Variables included in the multivariate analysis and their values. The value used as a reference is highlighted in bold.

Variable	Values
Gender	**Female**, Male
Age Group	**18-24**, 25-44, 45-64, 65+
Country	Italy, **South Africa**, United Kingdom, Brazil
Risk	Yes (have a risk factor for COVID-19, such as respiratory chronic diseases or immunocompromised state), **No**
Risk in household	Yes (have a person in household with a risk factor for COVID-19, such as respiratory chronic diseases or immunocompromised state), **No**
<18 in household	Yes (have at least one household member who is under 18 years old), **No**
>65 in household	Yes (have at least one household member who is above 65 years old), **No**
Positive Test	Yes (previously tested positive for COVID-19), **No**
Vaccine	Yes (received at least one dose of vaccine), **No**

Results

Sample composition

In Table 2 we report the demographic characteristics of the sample by country, before applying post-stratification weights. From these numbers are excluded participants that did not report age, sex and country but are included those not reporting other information (such as education or household size). Among the 2067 questionnaires, the majority comes from South Africa (47.9%), while Italy, the UK and Brazil account respectively for the 20.3%, 17.8%, and 13.9%. Compared to the overall population, the sex ratio is unbalanced towards female: this is particularly evident for Brazil where male participants represent only the 21.8 % of the total. On the contrary, UK is the country with the most balanced sample in terms of sex with 53.0% of responses from females and 47 % from males. The average participant's age is 56.7 (standard deviation 15.6, maximum value 93, median 61.0 and inter-quartile range 47-68). The average household size was 2.8 (standard deviation 2.2, inter-quartile range 2-4). With regards to educational attainment, Italy and Brazil show a majority of respondents with a secondary-level education (56.09% and 59.67%, respectively), while in South Africa and United Kingdom most respondents attained a university-level education (47.4% and 44.82%, respectively). For possible limitations of the sample composition, please refer to Section 4.

Table 2. Number of respondents by sex, age group, household size and education for each surveyed country. Unweighted sample.

		Italy	South Africa	United Kingdom	Brazil	Total
Sex						
	Female	261 (62.1%)	670 (67.7%)	195 (53.0%)	226 (78.2%)	1352(65.4%)
	Male	159 (37.9%)	320 (32.3%)	173 (47.0%)	63 (21.8%)	715 (34.6%)
Age						
	18-24	42 (10.0%)	27 (2.7%)	19 (5.2%)	49 (17.0%)	137 (6.6%)
	25-44	94 (22.4%)	132 (13.3%)	70 (19.0%)	48 (16.6%)	344 (16.6%)
	45-64	165 (39.3%)	438 (44.2%)	154 (41.8%)	119 (41.2%)	876 (42.4%)
	65+	119 (28.3%)	393 (39.7%)	125 (34.0%)	73 (25.3%)	710 (34.3%)

Household Size					
1	111 (26.4%)	150 (15.2%)	79 (21.5%)	52 (18.0%)	392 (19.0%)
2	117 (27.9%)	375 (37.9%)	160 (43.5%)	72 (24.9%)	724 (35.0%)
3-4	128 (30.5%)	303 (30.6%)	98 (26.6%)	100 (34.6%)	629 (30.4%)
5+	28 (6.7%)	135 (13.6%)	26 (7.1%)	47 (16.3%)	236 (11.4%)
No answer	36 (8.6%)	27 (2.7%)	5 (1.4%)	18 (6.2%)	86 (4.2%)
Education					
Primary school	8 (1.9%)	1 (0.1%)	4 (1.1%)	12 (4.2%)	25 (1.2%)
Secondary school	241 (57.4%)	447 (45.2%)	177 (48.1%)	179 (61.9%)	1044(50.5%)
University-level	159 (37.9%)	474 (47.9%)	165 (44.8%)	79 (27.3%)	877 (42.4%)
Other	1 (0.2%)	29 (2.9%)	4 (1.1%)	2 (0.7%)	36 (1.7%)
No answer	11 (2.6%)	39 (3.9%)	18 (4.9%)	17 (5.9%)	85 (4.1%)

Behavioral changes

Figure 2 shows the percentage of respondents by country (A), age (B) and sex (C) that reported a change in behaviors after the three key events of the vaccination campaign considered (vaccination of the population at risk and after the individual received first and second dose). Across the board, the activity that was changed the most is “Visit relatives and friends more frequently”, followed closely by “More frequent engagement in social activities”, such as going to restaurants, cinema, etc. On the contrary, “Reduced hygiene measures” (e.g., wash hands less often, use disinfectant gel less often) was the activity with the lowest percentage of change. Indeed, even after the second dose, the adoption rate exceeds 10% only in the United Kingdom. Similar findings can be observed for the two activities “Wear a face mask less often (where not mandatory)” and “Reduce the recommended physical distance (1 or 2 meters)”, for which the adoption rate is smaller than 30% across all countries and events. For this reason, in the multivariate analysis we focused our attention on social behaviors, defining behavioral change as the adoption of “Visit relatives and friends more frequently” or “Engage in social activities more frequently (e.g., going to restaurants)”.

For all the six activities considered, the adoption rate is higher after the second dose with respect to after the first one. Nonetheless, in Figure 2-A we can observe differences across countries. Indeed, Italy is the country where the population felt more comfortable to increase the use of public transport both after the first (28.2%) and the second dose (38.4%), while in Brazil the adoption rate was only 14.9% and 17.6% respectively. Furthermore, participants from Brazil were less prone to change their social behaviors.

For example, only 37.6%, reported an increase in visits to relatives and friends after the second dose, while the equivalent figure for Italy, UK and South Africa is above 50%.

Figure 2-B shows the adoption rate by age. Respondents under 25 years old were the most comfortable with reducing hygiene measure, the use of face masks and physical distance, and with using public transport more often, with a substantial increase in the adoption rate along with the progress of the vaccination campaign. On the contrary, people over 45 years old were less prone to relax social behaviors, in particular after the first and second dose.

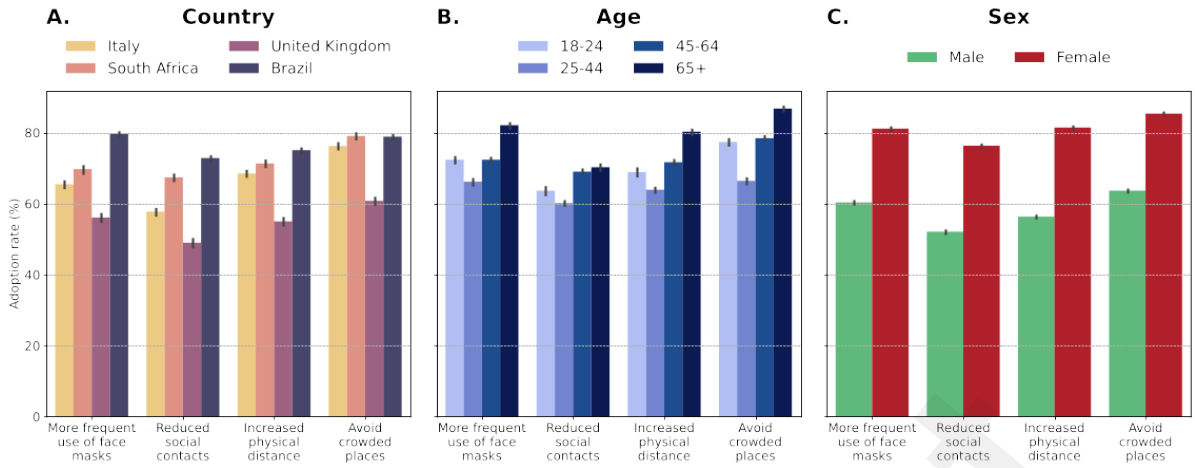
Finally, Figure 2-C shows differences in adoption rates by sex. Male respondents were more comfortable to adopt almost every activity after all the three stages of the vaccination campaign. The sole exception is represented by social behaviors for which, after the second dose, the adoption rate was quite similar for social activities in general (Male: 42.0%, Female: 40.3 %) but smaller for visits to relatives and friends it is even higher for females (Male: 43.1%, Female: 45.3%).

Figure 2. Adoption rate of behaviors after each stage of the vaccination campaign divided by country

(A), age group (B) and sex (C). The three stages considered are: the vaccination of people over 65 years old or with co-morbidities (Risk), the first dose (1st dose) and the second dose (2nd dose). Bar plots show mean values and 95% CI as error bars.

Figure 3 shows the adoption rate of preventive behaviors in case of a potential worsening of epidemiological conditions, by country (A), age group (B), and sex (C). Across the board, in the different cases considered more than half of the participants report that they would readopt COVID-safe behaviors in this hypothetical scenario. The United Kingdom shows the lowest adoption rate, exceeding 60% for avoiding crowded places only. When looking at the age breakdown in Figure 3-A, we note that people over 65 are the ones that would be more prone to readopt all the preventive behaviors. On the contrary, the age groups with the lowest adoption rate are 25-44 and 18-24. We also notice that reduction of social contacts is the preventive behaviors with the lowest adoption rate, as it is likely perceived as more costly to adopt. Indeed, the adoption rate of this behavior is under 70% for all age groups. Finally, on average, females would adopt preventive behaviors more than males, with a difference of at least 20% in the adoption rate between sexes.

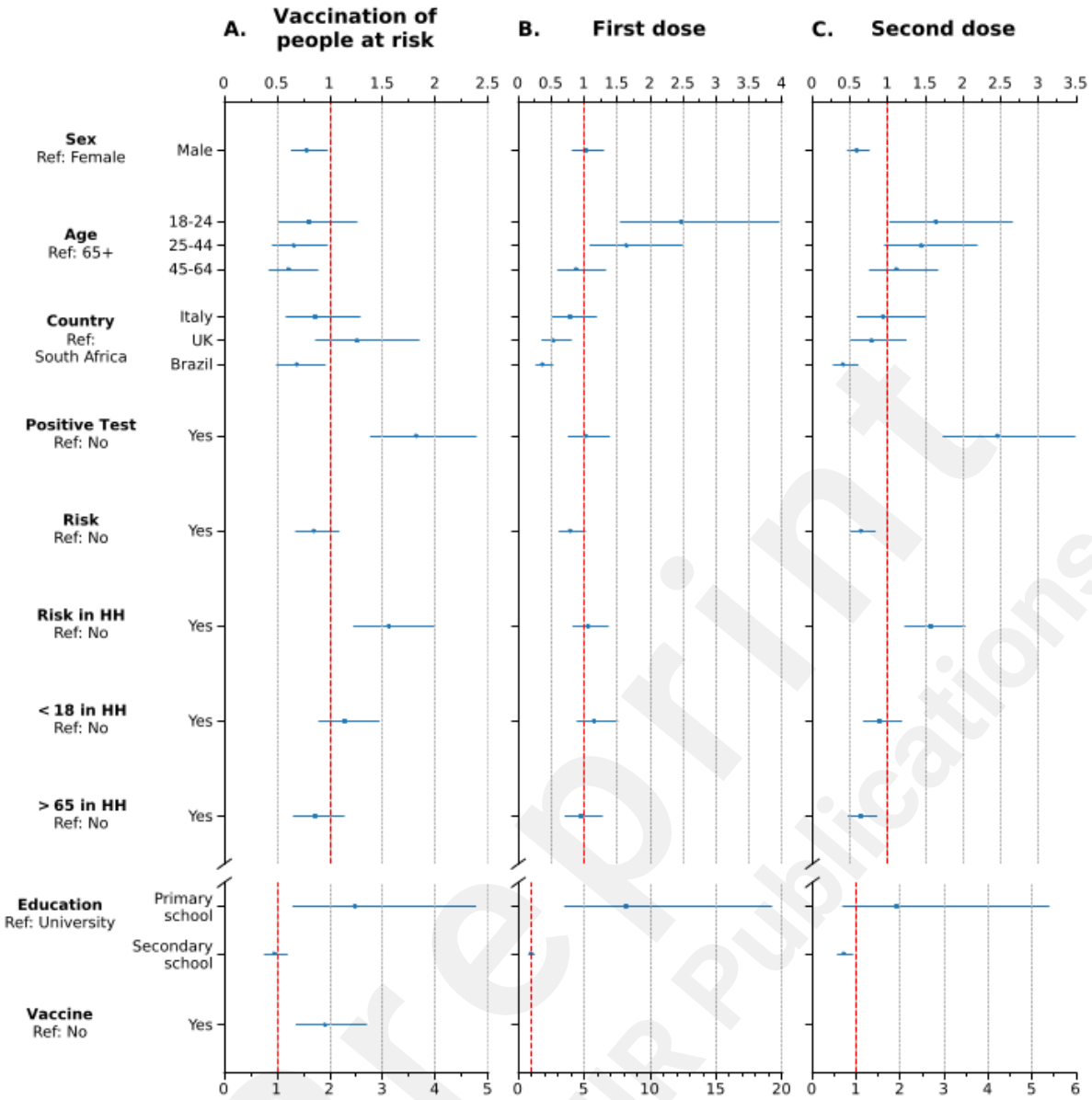
Figure 3. Adoption rate of preventive behaviors in case of a worsening of epidemiological conditions divided by country (A), age group (B) and sex (C). Bar charts show mean values as bars and bootstrapped 95% CI as errors.



Multivariate analysis

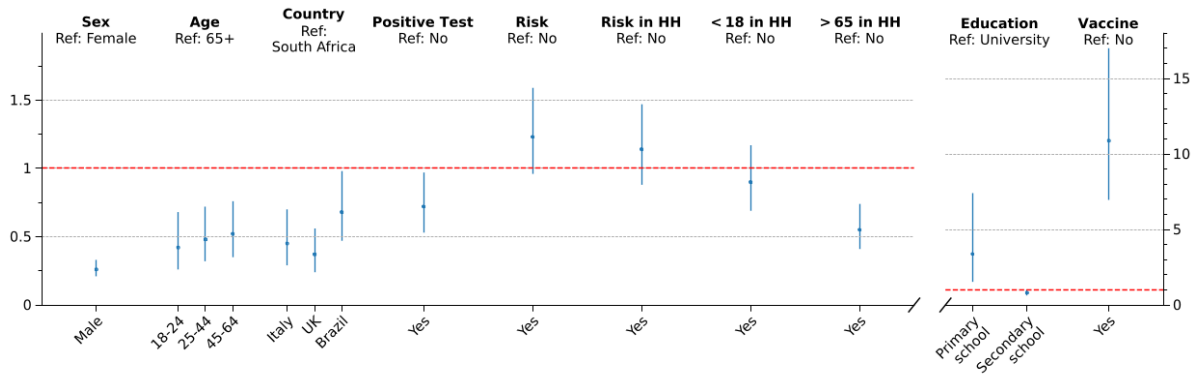
Figure 4 shows the odds ratio obtained from the multivariate analysis for changes in social behaviors after the three pivotal stages of the COVID-19 vaccination campaign. After the vaccination of elderly and people with comorbidities, having tested positive for COVID-19 is positively associated with a change in social behaviors (OR 1.82, 95% CI 1.38-2.39). This means that the odds of changing social behaviors for respondents that have been infected by COVID-19 are 1.82 times the odds in the rest of population. A similar result is obtained for the feature Risk in HH (Risk in household). Indeed, having people at risk in the household is positively associated with a change in at least one of the two social activities (OR 1.56, 95% CI 1.22-1.99). Other features that are positively associated with the outcome are being vaccinated (OR 1.91, 95% CI 1.35-2.7) and a primary school level education or lower (OR 2.48, 95% CI 1.29-4.77).
After the first dose, younger age groups engaged more frequently in social activities and visited parents and friends more often. Indeed, the odds of a relaxation of social behaviors in age group 18-24 are 2.47 times (95% CI 1.54-3.96) the odds of change in 65+. Age group 25-44 and a primary school level education or lower are also positively associated with an increase in social activities. Respondents from UK and Brazil have lower odds to change social behaviors than respondents from South Africa.
After the second dose, having tested positive for COVID-19 (OR 2.46, 95% CI 1.73-3.49) and having people at risk within the household (OR 1.57, 95% CI 1.22-2.03) are positively associated with a change in social behavior. On the other hand, the odds of these changes are lower for male respondents (OR 0.59, 95% CI 0.46-0.76), people at risk (OR 0.65, 95% CI 0.5-0.84), respondents from Brazil (OR 0.41, 95% CI 0.27-0.61) and those with a secondary school level education (OR 0.72, 95% CI 0.56-0.93).

Figure 4. Odds ratio obtained from multivariate analysis of the survey responses related to behavioural changes after the vaccination of people over 65 years old or with comorbidities (A), after the first dose (B), and after the second dose (C). The outcome considered is: 1 if there was a change in at least one of the two social activities, 0 otherwise. Details about the features are reported in Table 1.



Finally, in Figure 5 we report the odds ratio for the hypothetical scenario of a worsening of epidemiological conditions. In this case, the binary outcome is 1 if the participant would adopt all four NPIs proposed in the scenario, and 0 otherwise. All age groups are less likely to adopt all the NPIs when compared to 65+ years old group and the same goes for male respondents respect to female ones. Other features have a negative association, namely: being a respondent from Italy, the UK or Brazil, having tested positive and having a household member aged over 65 years old. On the contrary, respondents with a primary school level education or lower are more likely to adopt all four NPIs. However, the feature with the strongest positive association is the vaccination status. The odds of adopting all four NPIs in case of a worsening of epidemiological conditions for people who are vaccinated are 10.88 times higher (95% CI 6.96-17.01) than the odds for people who are not vaccinated.

Figure 5. Odds ratio obtained from multivariate analysis of the answers related to behavioral changes in case of a worsening of epidemiological conditions. The outcome is 1 - adoption of all 4 NPIs proposed, 0 - otherwise. Details about the features are reported in Table 1.



Discussion

Principal Results

We found that a significant portion of participants relaxed NPIs during the vaccination campaign. In good accordance with the Health Belief Model, the two social activities were the ones that witnessed the greatest changes. Indeed, stronger relaxation of NPIs in social contexts can be explained considering their high perceived cost (i.e., high perceived barriers in the HBM model) which makes them difficult to be adopted for a long period. On the other hand, the majority of individuals kept adopting personal activities such as hygiene measures and use of face throughout the duration of the vaccination campaign. These measures have indeed smaller costs associated and thus are easier to implement. This finding also shows how, after almost two years in a pandemic, face masks have become widely adopted and accepted also in countries where they have rarely been used before such as Italy.

We observed age- and sex-specific patterns. After the first and second dose, older respondents were far less incline to relax their protective behaviors with respect to younger ones. Older people also reported the highest adoption rate of NPIs in an hypothetical worsening of epidemiological conditions. This is consistent with the HBM, where perceived severity is one of the driving factor of the adoption of health-behaviors. Indeed, older adults are at higher risk of severe symptoms from COVID-19 [CITATION biswas2021association \l 1033][CITATION kang2020age \l 1033].

We found that females reported smaller changes in NPIs with respect to males. Consistently, in the multivariate analysis we obtained that being female was positively associated with a change in social behaviors after the second dose. In the case of a worsening of epidemiological conditions, the difference is considerable: the adoption rate of NPIs is at least 15% higher among females than males. These results are in line with previous ones in the context of COVID-19 [CITATION perrotta2021behaviours \l 1033][CITATION galasso2020gender \l 1033] or flu [CITATION bish2010demographic \l 1033], where females were found to be more inclined to adopt preventive behaviors. However, it is important to notice that, while susceptibility to COVID-19 infection is similar between males and females, males experience a higher severity and fatality for COVID-19 infection [CITATION mukherjee2021covid \l 1033][CITATION islam2021excess \l 1033].

Two of the most important determinants for the drop of social NPIs are i) having tested positive for SARS-CoV-2 and ii) having people at risk in household. Indeed, both these features are positively associated with a change in social behaviors after the vaccination of vulnerable population and after the second dose. This is probably due to the fact that after recovering from COVID-19, individuals are less worried to get the virus again or spread it and, as a consequence, they relax their social behaviors. On the other hand, having people at risk in household may impact the perceived threat of individuals and can lead them into having a particularly careful behavior in order to protect them. Therefore, after the vaccination of these people or after their own vaccination individuals may have felt safe (smaller perceived susceptibility and severity) to partially relax their protective behaviors.

However, it is interesting to notice that being at risk is negatively associated with a drop in social NPIs after the second dose. Therefore, while people around them felt safer to engage more frequently in social activities, individuals with a risk condition did not on average. Finally, it is interesting to focus on the vaccination status. Obviously, this has not been used as a feature to analyse change in behavior after first and second dose sinche these questions were available only for vaccinated people. We found that being vaccinated is positively associated with a drop in social NPIs after the vaccination of over 65 and people with comorbidities. This can be explained considering that this question was available also to all those people who got vaccinated because of their risk condition (age or comorbidities). After being vaccinated these people probably felt more protected and as a result relaxed their behaviors. On the contrary, being vaccinated is positively associated with adoption of NPIs in case of a worsening of epidemiological conditions. The association is really strong: vaccinated people are 10.88 times more likely to adopt all the COVID-19 safe behaviors examined than not vaccinated people. This is concerning because individuals that are not vaccinated, in addition to be less protected against COVID-19 from a pharmacological side, also lack a behavioural protection as they would be less likely to adopt safer behaviors, exposing themselves at a higher risk of infection.

Limitations

While the sensitivity analysis in the Supplementary shows that our results are solid, there are limitations to our work. First, responses obtained via online surveys administered on Facebook or other social medias are typically not representative of the general population [CITATION mellon2017twitter \l 1033][CITATION kalimeri2019evaluation \l 1033][CITATION whitaker2017use \l 1033]. To mitigate this issue, we carefully planned the data collection through Facebook advertisements targeted homogeneously across different demographic groups. The reliability of such targeting criteria for recruiting participants for survey research have been assessed in previous studies [CITATION grow2022facebook \l 1033][CITATION rosenzweig2020survey \l 1033]. Moreover, we applied post-stratification weights in order to correct for the remaining imbalances, at least in central observable characteristics, such as age, sex, and region of residence. Furthermore, we acknowledge possible self-selection bias of online survey respondents and under-representation of minority. Another important element to consider is the language used for ads and surveys: English, Italian and Portuguese. While these are the official languages of the four countries we focused on, this limited language availability may have caused under-representation of specific groups. This is especially true for South Africa, where English is the main language of only a fraction of the population, despite being understood from more than half of the population and being the most common language in urban areas.

Conclusions

Non-pharmaceutical interventions have played a pivotal role in the first year of the COVID-19 pandemic, slowing the disease progression while vaccines were being developed and tested. Even after the start of the vaccination campaigns, NPIs remained essential [CITATION galanti2021social \l 1033]. Indeed, due to limited supplies (especially in low and middle income countries [CITATION moore2022retrospectively \l 1033][CITATION mobarak2022end \l 1033][CITATION duan2021disparities \l 1033][CITATION bayati2022inequality \l 1033][CITATION gozzi2022estimating \l 1033]) and unprecedented logistic challenges, NPIs were key to mitigate the disease burden as vaccinations progressed [CITATION galanti2021social \l 1033][CITATION gozzi2021importance \l 1033][CITATION moore2021vaccination \l 1033][CITATION patel2021association \l 1033][CITATION yang2021despite \l 1033]. Nevertheless, the milestone marked by the arrival of effective vaccines, in a background of pandemic fatigue, might have affected risk perception of segments of the population inducing a reduction in NPIs compliance

[CITATION andersson2020anticipation \l 1033]. Several modelling efforts highlighted the potential negative effects of such phenomenon, but empirical evidence for it is still limited. Here, we tackled this limitation by investigating whether individuals relaxed behaviors during the vaccination campaign using an online survey administered via Facebook, collecting more than 2000 responses across four countries. Moreover, to understand the role played in the relaxation of NPIs by different social and demographic characteristics, we performed a multivariate analysis focusing on the drop of NPIs in social contexts. We showed a significant relaxation of COVID-19 safe behaviors, in particular social activities, and we found that main determinants of these changes are generally connected to shifts in perceived risk. Therefore, great caution should be taken during a mass vaccination campaign like the one we experienced in the last years. Indeed, spontaneous relaxation of NPIs by the population can jeopardize the incredible benefits of the immunization campaign which, however, are not immediate and are visible in the medium term especially in challenging and emergency contexts. For this reason, it is extremely important for policymakers to keep high the compliance with NPIs in the first phase of a vaccination campaign through targeted actions and efficient communication.
Ultimately, our results can also be used to inform and design more advanced, data-driven epidemic-behavior mathematical models able to capture more accurately the spread of the virus, the behavioral reaction of individuals, and the progress of the vaccination campaign.

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Contribution:

Conceptualization: ADG, PB, NG, NP, DPE, DPA
Survey design: ADG, PB, NG, NP, DPE, DPA
Data collection: ADG
Statistical analysis: ADG
Writing: ADG
Revision and approval of the manuscript: all authors reviewed and approved the manuscript

Conflicts of Interest

None declared.

Abbreviations

CI: Confidence interval
NPIs: Non pharmaceutical interventions
HBM: Health Belief Model
GLM: Generalized Linear Model
UK: United Kingdom

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Supplementary Files

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Multimedia Appendixes

Supplementary material.
URL: http://asset.jmir.pub/assets/aebd910057a955f514c2b5f73029a3d5.pdf

English version of the questionnaire.
URL: http://asset.jmir.pub/assets/c9ca94a001c0f1f0ce6f1da0ce77645f.pdf

Informative data about each country included in the study (Source: [25]) with the dates of the beginning of the advertising campaigns.
URL: http://asset.jmir.pub/assets/a1a9f33d947493b1931617532316e8e4.png

Adoption rate of behaviors after each stage of the vaccination campaign divided by country (A), age group (B) and sex (C). The three stages considered are: the vaccination of people over 65 years old or with co-morbidities (Risk), the first dose (1st dose) and the second dose (2nd dose). Bar plots show mean values and 95% CI as error bars.
URL: http://asset.jmir.pub/assets/2db20a31e70f552ea6598d26bb4438c5.png

Adoption rate of preventive behaviors in case of a worsening of epidemiological conditions divided by country (A), age group (B) and sex (C). Bar charts show mean values as bars and bootstrapped 95% CI as errors.
URL: http://asset.jmir.pub/assets/2e9207309807717fbcc34d1a9826ef59.png

Odds ratio obtained from multivariate analysis of the survey responses related to behavioural changes after the vaccination of people over 65 years old or with comorbidities (A), after the first dose (B), and after the second dose (C). The outcome considered is: 1 if there was a change in at least one of the two social activities, 0 otherwise. Details about the features are reported in Table 1.
URL: http://asset.jmir.pub/assets/8f34d15663864712e112369f5a62518b.png

Odds ratio obtained from multivariate analysis of the answers related to behavioral changes in case of a worsening of epidemiological conditions. The outcome is 1 - adoption of all 4 NPIs proposed, 0 - otherwise. Details about the features are reported in Table 1.
URL: http://asset.jmir.pub/assets/145cbed20f0c6324635f67d91ed430ae.png