Attitudes Towards COVID-19 Contact Tracing Apps: A Cross-National Survey

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ABSTRACT To help prevent the spread of COVID-19, countries around the world have implemented a range of measures and virus containment strategies, including digital contact-tracing (DCT) in the form of smartphone apps. While early studies showed a high level of acceptability of such technologies, the adoption rates varied greatly between countries after contact-tracing apps became available to download. This cross-national user survey (n=871) aims to explore public attitudes and factors that affect user acceptability and adoption of contact-tracing apps in the USA, UK, and the Republic of Ireland, which employ similar underlying technology, but have uneven adoption rates. The results indicate interactions between installation decisions and public trust in actors and institutions communicating COVID-related information, and releasing such technologies. Beyond the immediate case of contact tracing, our findings hold implications for the deployment and communicative framing of technology for public health and the public good, and inform the design of crisis response public health information systems.

INDEX TERMS COVID-19, exposure notification, digital contact tracing, crisis informatics, mHealth, online survey, public views, quantitative methods.

I. INTRODUCTION

The outbreak of SARS-CoV-2 has caused an epidemic of acute respiratory syndrome (COVID-19), infecting millions of people globally. To save lives and stop health systems from being overwhelmed, governmental authorities around the world have implemented various policies, ranging from recommendations and relatively mild measures, such as enhanced hand hygiene or mandatory face masks, to far-reaching measures restricting human activity (lockdowns and travel bans) [1], [2]. However, lockdowns entail high socio-economic costs [3], [4], and with limited healthcare resources and uncertainty caused by new strains of COVID-19, the pandemic has spurred the deployment of innovative information systems (IS) to help prevent further spread of the disease.

One such IS solution is digital contact tracing (DCT), which has been introduced in many countries to assist and supplement manual contact-tracing. Contact tracing involves identifying and informing individuals who have come in contact with a COVID-19 positive patient. Previous research estimated that feasible and scalable manual COVID-19 contact tracing in a large multistate health system in the United States would employ approximately 69,000 health care personnel [5]. Modelling studies indicate that augmenting this process with the introduction of DCT could reduce mean transmission by 47% [6].

There are two approaches in implementing digital contact tracing: centralized systems, which store all contact tracing information on a central server, and distributed systems, which store data in individuals’ smartphones [7] or in...
an alternative distributed format [8]. While a centralized approach is more efficient [9] and more robust to some security attacks [10], it poses privacy risks to users’ personal data [9], and most European and US contact-tracing apps are implemented as distributed systems. For instance, free, distributed contact-tracing apps have been made available in the US, the UK, and the Republic of Ireland, and are used on a voluntary basis. These are based on the Google and Apple API, and use Bluetooth Low Energy (BLE) technology to measure the distance and the duration of contact between smartphones that have the app installed, without revealing any names or identities of people or their location.

While DCT apps were mostly released by official governmental or public health authorities,¹ and early surveys in spring and summer 2020 showed high acceptance rates for their hypothetical use [11], [12], recent research reports uneven rates of adoption once the apps became available to download [13]–[15]. In the analysis of factors that influence uptake, previous research identified DCT implementation concerns, such as contact detection accuracy and reliability or battery consumption [16]. Security of personal data in DCT apps, as well as privacy issues related to trust and transparency, were other prominent user concerns [17]. These concerns have been demonstrated in countries with a voluntary model and low trust index toward their governments, such as Australia, the United Kingdom and Germany, where citizens have shown more resistance to downloading and using the apps [18]. Moreover, the COVID-19 pandemic has incited a flood of “fake news” and conspiracy theories, which has been described as an “infodemic” of disinformation by the World Health Organization (WHO) [19]. Disinformation, and the lack of clear ethical, legal, and technical safeguards, as well as the lack of unanimous consensus on the utility of contact-tracing apps, have polarized the public debate and triggered the propagation of conspiracy theories and uncertainty on the use of such apps beyond the pandemic. Concerns include DCT misuse for political purposes [20] or mass surveillance [7]. From one perspective, this indicates the importance of taking into account information sources and trust when understanding the factors contributing to installation decisions. From another perspective, it highlights the importance of transparency and accessibility in information provision regarding measures such as DCT.

The objective of this study is to identify the factors that affect user acceptability and adoption of contact-tracing apps in three countries: the UK, the USA, and the Republic of Ireland. The user survey aims to explore public attitudes to the uptake, previous research identified DCT implementation concerns, such as contact detection accuracy and reliability or battery consumption [16]. Security of personal data in DCT apps, as well as privacy issues related to trust and transparency, were other prominent user concerns [17]. These concerns have been demonstrated in countries with a voluntary model and low trust index toward their governments, such as Australia, the United Kingdom and Germany, where citizens have shown more resistance to downloading and using the apps [18]. Moreover, the COVID-19 pandemic has incited a flood of “fake news” and conspiracy theories, which has been described as an “infodemic” of disinformation by the World Health Organization (WHO) [19]. Disinformation, and the lack of clear ethical, legal, and technical safeguards, as well as the lack of unanimous consensus on the utility of contact-tracing apps, have polarized the public debate and triggered the propagation of conspiracy theories and uncertainty on the use of such apps beyond the pandemic. Concerns include DCT misuse for political purposes [20] or mass surveillance [7]. From one perspective, this indicates the importance of taking into account information sources and trust when understanding the factors contributing to installation decisions. From another perspective, it highlights the importance of transparency and accessibility in information provision regarding measures such as DCT.

1 Some DCT apps emerged from crowdsourcing or academic efforts.

The objective of this study is to identify the factors that affect user acceptability and adoption of contact-tracing apps in three countries: the UK, the USA, and the Republic of Ireland. The user survey aims to explore public attitudes to the governmental response to the COVID-19 outbreak, as well as participants’ attitudes to such apps, including their concerns and COVID-19 information preferences. By developing a better understanding of the factors that enable and prevent DCT uptake, our work contributes to crisis informatics and public health research. Moreover, by exploring cross-national user views on such information systems as DCT, we provide a roadmap for ongoing and future crisis-response digital public health systems.

II. BACKGROUND

Previous studies indicate that contact tracing, followed by treatment or isolation, has been an effective measure to slow the spread of the COVID-19 [6]. However, manual contact tracing is time and resource intensive, and can be prone to errors [21]. These limitations raised an interest for technology to support this work – digital contact tracing (DCT) or exposure notification [6]. The role of DCT is to speed up tracing and to identify more potentially exposed contacts per index case. Simulation models and recent real-life data indicate that a combination of manual and contact tracing smartphone applications (apps) is more efficient compared to only manual contact-tracing [22], [23].

While the effectiveness of digital contact tracing strongly depends on adoption and continuous use [24], [25], achieving mass voluntary acceptance of this technology has been a substantial challenge for governments all over the world [26], [27]. Countries such as the Republic of Ireland, the UK, and the USA are among those that have launched contact tracing apps on an opt-in (voluntary installation) basis. While the technical characteristics of the apps are similar, the rates of adoption have varied substantially. In the Republic of Ireland, by September 2020 around 1.28 million people downloaded the contact-tracing app [28], which is roughly 25.7% of the total population of the Republic of Ireland. As for the UK, based on the information from the Department of Health and Social Care of September 2020, over 10 million people in England and Wales have downloaded the NHS app [29] (one of three apps available, among those in Scotland and Northern Ireland), roughly 17% of their population. In the US, the uptake varied from state to state with around 8.1 million installations in total by December 2020 [30], about 2.4% of the total US population.

Previous research focused on technical specifications of COVID-19 tracing apps [31]–[33], modelling their efficacy in identifying close contacts [24], [25] and epidemiological impact [34], but fewer studies have examined the factors that affect the adoption of COVID-19 tracing apps after their release. Digital health acceptability tends to change from pre-use to initial use stages [35]. Post-release attitudes towards such technologies can influence their potential use, and their efficacy highly depends on uptake. Hence, it is important to understand what categories of populations chose to use and not to use contact-tracing apps and why.

Variance in acceptability and adoption of DCT has been documented in both the human-computer interaction and medical intervention literature on digital health. Previous pre-release studies explored public attitudes – including perceived benefits and potential issues – to such apps in specific countries, e.g. in the UK [36], Republic of Ireland [17], or Singapore [37]. There is an evident need for cross-cultural studies of technology acceptance [38], and other pre-release work has investigated cross-national
intentions to install such apps: Altmann et al. found strong support for contact-tracing apps in all studied countries (France, Germany, Italy, the United Kingdom, and the United States) [11]. A survey by Georgieva et al. investigated perceived effectiveness, restrictiveness, and compliance with government-imposed measures across 11 countries (UK, Belgium, Netherlands, Bulgaria, Czech Republic, Finland, India, Latvia, Poland, Romania, and Sweden) and identified that perceived effectiveness of contact-tracing procedures greatly outweighed its perceived restrictiveness [2].

These works highlight various factors that affect the acceptability of DCT. Those with privacy and security concerns, as well as lower levels of trust in their national government are less likely to be in support of app-based contact tracing [11]. Social influence [39] and social orientation (collectivist or individualist) [40] also affect the intention to use such apps. Personal experience with the virus was found to correlate with the likelihood to support contact-tracing apps and expanded surveillance in general [41]. However, there is still little known about the determinants of actual adoption of contact tracing apps post-release, the barriers to installation, and how those barriers could be overcome. A few recent works have addressed these issues by conducting studies after contact-tracing apps became available to install, investigating users’ views and acceptability [42], related privacy concerns [43], as well as the usability of such apps [44]. Blom et al. identified rather pessimistic public views on the effectiveness of app-based contact tracing in Germany, and the low uptake among demographic groups with high potential to spread the virus [45]. Another important study investigating the factors related to app uptake is by Munzert et al.: a longitudinal survey on contact-tracing app usage in the German context [46], which indicates that older populations and people with medical conditions are more likely to adopt the app. While previous acceptability studies show that younger adults are willing to install the app [11], this survey found that those with a higher degree of social exposure are less likely to install it. Instead, in line with earlier studies, those who trust their national government are more likely to adopt the app. Other studies have also provided recommendations on facilitating the adoption of such apps, for instance, through social influence and media campaigns, as was the case in Canada and New Zealand [47].

The deployment of digital public health technologies to track and mitigate the spread of COVID-19 is an interesting, ambitious, and largely unprecedented use of massive-scale citizen data at a population level. It implies both a personal and public benefit, but also amplifies concerns for the intrusion of governmental authorities upon citizens’ privacy.

Based on the findings from previous research, we anticipate the decision to install contact-tracing apps is likely to be related to the attitudes to governmental response and policies, trust in authorities, preferences for sources of pandemic-related information, and demographic characteristics. It is also evident that questions related to information provision are important to consider when trying to understand public uptake reasoning, as well as the specifics of different governmental responses in implementing DCT strategies.

We, therefore, define the following five research questions (RQs) addressing country-level and individual-level variation in support for the app.

**RQ1:** Do trust in authority groups, personal experience with COVID-19, and news source preference predict contact-tracing app installation? As previous research indicates the correlation of DCT acceptability with trust in governmental authorities in hypothetical use scenarios, we expand authority groups by including other relevant actors and explore whether the same holds after such systems have been introduced. Moreover, we investigate whether personal experience with COVID-19 (having contracted the disease or variables related to pandemic experience) influences acceptability views, as well as trust and preference towards certain information sources, which provide pandemic updates.

**RQ2:** Do participants’ perceptions of the efficacy of their personal or national-level actions to limit the spread of the virus or evaluation of official pandemic response correlate with app installation? In the Republic of Ireland, the UK, and – to a certain extent – in the US, DCT systems were introduced by governmental authorities. We aim to study whether public views of personal and governmental efficacy in containing the virus affect the acceptability of DCT apps.

**RQ3:** Do news source preferences correlate with app awareness? Previous research indicates the role of media in promoting public health measures and steering or even polarising public views related to pandemic crisis response initiatives. We investigate whether preference for certain news channels and trust in the accuracy of their information affects the awareness of DCT apps.

**RQ4:** Do demographic characteristics, such as age, gender or English as a first language (EFL), predict DCT app acceptability? Previous research on hypothetical scenarios of DCT systems indicates that certain demographic groups might show more or less support for such apps. We investigate whether specific demographic factors predict app adoption.

**RQ5:** Finally, we investigate whether trust in authority groups and actors, such as public health authorities or scientists, correlates with compliance with the guidelines provided by DCT application alert features.

### III. METHODS

We conducted a cross-national online survey in three countries – the United Kingdom, Republic of Ireland, and the United States – to explore public attitudes and the acceptability of digital app-based contact tracing for COVID-19 after such apps became available to download in the three countries.

In Section IV, we describe the underlying functionality and technical characteristics of the state-released DCT apps indicating the similarities in all three countries. However, the number of such DCT apps and their distributors in the studied countries varied. One national DCT app was released in the
Republic of Ireland (COVID Tracker), the official UK DCT initiative included three apps (England and Wales, Northern Ireland, and Scotland) launched by public health authorities, and in the US, at the time of the study, state-released contact-tracing apps were available in 21 out of 52 states.\(^2\) We also acknowledge the potential availability of DCT initiatives other than national or state-released that might have affected respondents’ awareness of DCT efforts (and, consequently, adoption), such as academic or crowdsourcing efforts, but in this study, we focus on the acceptability of DCT apps regardless of their distributors, as can be seen in the survey design available in Appendix. Moreover, in the case of the US respondents, we do not restrict them to the state-level, asking about their awareness of DCT apps in their country of residence consistently with other countries.

The surveys were administered between the 12th of January and the 26th of February, 2021, which corresponded to full lockdown measures implemented in the UK, the Republic of Ireland, and some of the states in the USA. During the studied period, COVID-19 vaccination had just started in all three countries, targeting only the most vulnerable population groups, such as older adults or individuals with health conditions that put them at increased risk.

### A. SURVEY DESIGN

A 49-item online survey was released via Qualtrics XM survey software [48]. A complete description of the survey can be found in Appendix; here, we provide an overview.

At the start of the survey, after collecting respondents’ informed consent, they were asked questions related to their personal experience with COVID-19, beliefs in their personal and collective efficacy in limiting the spread of the virus (whether their or others’ actions taken to limit the spread of the virus make a difference), their use of information sources related to COVID-19, and their smartphone use and associated ICT skills. Respondents were then asked about their knowledge of contact-tracing and DCT apps. If they did not know what these are, we provided them with brief definitions (Appendix), which also served as a potential reminder if they were not sure or forgot what these mean. Then, the respondents were asked about their awareness of the availability of such apps in their country of residence (“Do you know of any apps that help track the spread of COVID-19 in your country?”). Based on the answer to this question, we directed them to the questions related to their intention to install such apps: a hypothetical question “if such apps would be available in your region…” or a more concrete assessment of installation if they “know about the app/apps in their region” (see Appendix). We then proceeded with questions on trust and attitudes to governmental and other institutions. The survey was concluded by collecting demographic information and providing participants with relevant resources regarding contact tracing in their country.

The majority of the questions were based on those used in previous studies. Three questions on the acceptability of a contact-tracing app and one question on compliance were adapted from the Oxford University survey [49]. Two questions on trust and preference of the news sources were adopted from the survey of Gruzd and Mai [50]. Finally, the questions related to smartphone use and intentions, as well as reasons for and against the installation of the app, were adapted from the studies of O’Callaghan et al. [17] and Abeler et al. [49].

The study has been reviewed and received a favourable opinion from the Research Ethics Committee (REC) of the School of Computer Science and Statistics of Trinity College Dublin (reference number 20200803).

Survey participant recruitment took place online through a combination of recruitment through Prolific (an online panel provider), social media platforms (Twitter, Facebook, Instagram, Reddit, and LinkedIn), online volunteer advertising sites, advertisement on Irish radio stations, university message boards, Trinity College Dublin online platforms, academic newsletters, and snowball sampling. Surveys were advertised in various regions and cities across all three countries. Specific demographic groups were not targeted beyond the specific geographic regions of residence (UK, USA, and the Republic of Ireland) and participants older than 18 years.

### B. DATA ANALYSIS

All analyses were carried out in R v4.02 [51]. Descriptive statistics are used to present the findings of demographics, as well as awareness and adoption of the contact-tracing apps by the respondents. A Logistic Regression model was created for the identification of the factors that correlate with the installation of a contact tracing application. This was chosen due to the expected normality of data distribution and the binary dependent variable. A Logistic Regression model was also created for the analysis of factors in awareness of a DCT application. For supplementary categorical data analyses, a CHI squared test with a Bonferroni Correction was used. A Spearman’s rank correlation was used where both the dependent and independent variable were incremental ordinal Likert scores to assess for correlative relationships. Answers to open questions were analysed using thematic analysis.

### IV. CHARACTERISTICS OF CONTACT-TRACING APPS IN STUDIED COUNTRIES

In this section, we summarise the technical characteristics and functionality of state-released DCT apps in three studied countries at the time of the survey. While we acknowledge the potential availability of other DCT solutions, which could be produced by academic or crowdsourcing efforts, their evaluation was out of the scope of this study.

\(^2\)At the time of the study, these states included Alabama, Arizona, California, Colorado, Connecticut, Delaware, District of Columbia, Hawaii, Maryland, Michigan, Minnesota, Nevada, New Jersey, New York, North Carolina, North, Dakota, Pennsylvania, Virginia, Washington, Wisconsin, and Wyoming.
A. REPUBLIC OF IRELAND

In the Republic of Ireland, the official “COVID Tracker” [52] app was developed by NearForm3 and launched by the Irish government on the 7th of July, 2020.

Underlying Functionality: Built on the Google and Apple Exposure Notification API (GAEN), “COVID Tracker” uses Bluetooth and anonymous IDs to log phones (with the app) that are in close contact tracking the distance and the time elapsed. Every 2 hours, the app downloads a list of anonymous IDs that have been shared with the Health Service Executive (HSE) by other users that have tested positive for COVID-19. If a user has been closer than 2 m for more than 15 min with any of these phones, they will get an alert that they are a close contact. The app runs in the background.

Beyond the core contact tracing functionality, users can choose to log daily health status or symptoms via the Check-In option, and also to share their age, group, sex, locality, and a contact phone number so the HSE can contact them. The app provides daily updates on COVID cases in Ireland and general information on COVID-19.

Notification: “COVID Tracker” users are notified and instructed to restrict their movements or self-isolate if they have been in close contact with another user confirmed to have COVID-19. If users shared their phone number at the point of setting up the app, then after receiving the app alert, a contact tracing team calls them to arrange a free COVID-19 test. Users are requested to call the COVID-19 helpline otherwise.

B. UNITED KINGDOM

Initially, the UK government proposed a “centralized model”, where contact data are stored in a central database and not exclusively on the phones themselves. On the 12th of April, 2020, the UK government announced the new centralized NHSX (the technology arm of the UK’s National Health Service) contact tracing app, a pilot trial of which was launched on the Isle of Wight (a small island with a population of approximately 140 000) on the 4th of May, 2020 [53].

The centralized approach contrasted with the version developed by the major technology companies Apple and Google (a “decentralized approach”), where contact information is only stored on users’ phones. On the 18th of June, the UK government abandoned its app, in favour of the decentralized model, after releasing details of a number of problems identified in the pilot, including the fact that when used on Apple iPhones, only around 4% of contacts were successfully identified. The new, decentralized app was later officially released on the 24th of September, 2020.

Northern Ireland’s “StopCOVID NI” contact tracing app was launched on the 30th of July, 2020 and Protect Scotland in Scotland on the 10th of September, 2020. Similarly to the Republic of Ireland, the contact tracing apps for Northern Ireland and Scotland were developed by NearForm.

Underlying Functionality: The main function of all UK apps is digital contact tracing using the privacy-preserving Google Apple Exposure Notification (GAEN) system, embedded in the Android and iOS operating systems, supplemented with custom Bluetooth processing algorithms. The “NHS” app uses Bluetooth low energy technology along with GPS to track the movement of users [54].

NHS app functions include providing locally appropriate information on COVID-19 prevention, checking into venues using a custom QR code scanner (allowing later notification if users have visited venues with a confirmed case), and a symptom checker linked to the booking of tests. For tests booked through the app, the test result triggers a set of actions automatically, including notification of the tested individual through the app, and digital contact tracing for positive results (upon the user’s approval).

Notification: The users of UK apps are notified and instructed to quarantine if they had contact with another user later confirmed to have COVID-19 if the exposure had characteristics that exceed a risk threshold.

C. USA

In the USA, Google and Apple’s interoperable COVID-19 contact tracing app was released on the 20th of May, 2020, and by the beginning of December 2020, nearly half of US states had their state-released contact-tracing apps available to install. At the time of the study, DCT apps were released by the state governmental authorities in the following states: Alabama, Arizona, California, Colorado, Connecticut, Delaware, District of Columbia, Hawaii, Maryland, Michigan, Minnesota, Nevada, New Jersey, New York, North Carolina, North Dakota, Pennsylvania, Virginia, Washington, Wisconsin, and Wyoming.

While some apps were state-specific, for example, California’s “CA Notify” and Virginia’s “COVIDWise”, others formed a regional alliance of apps with a common codebase, as was the case with New Jersey, New York, Pennsylvania, and Delaware. US contact-tracing apps were developed by several different companies and governmental authorities, for instance, WeHealth (“COVID Watch” in Arizona), PathCheck (“PathCheck Safe Places”), or Nearform (Pennsylvania, New York, New Jersey, Delaware “COVID Alert”). In this study, we explore the awareness and, consequently, adoption or hypothetical acceptability of the DCT apps in the US participants on the country rather than specific state level (“Do you know of any apps that help track the spread of COVID-19 in your country?”).

Underlying Functionality: Similarly to the UK and Republic of Ireland, US contact tracing apps are based on Google Apple Exposure Notification (GAEN) system. Typically, an app downloads tokens from the server from the devices of users who have anonymously reported a positive test. Users’ phones then use their records of the signal strength and duration of exposures with those tokens to calculate risk and determine if a user has met a threshold to receive an Exposure Notification.

3https://www.nearform.com/
TABLE 1. Demographic characteristics of survey respondents (N = 871).

| Attribute           | Range         | Sample size |
|---------------------|---------------|-------------|
| Gender              |               |             |
| Female              | 581 (66.7%)   |             |
| Male                | 264 (33.3%)   |             |
| Non-binary          | 17 (1.9%)     |             |
| Prefer not to disclose | 7 (0.8%)  |             |
| Prefer to self-describe | 2 (0.2%)  |             |
| Age                 |               |             |
| 18-30               | 460 (52.9%)   |             |
| 31-40               | 191 (21.9%)   |             |
| 41-50               | 118 (13.6%)   |             |
| 51-60               | 67 (7.7%)     |             |
| 61-70               | 26 (2.9%)     |             |
| >71                 | 8 (0.9%)      |             |
| Ethnicity           |               |             |
| White               | 681 (78.2%)   |             |
| Asian               | 76 (8.8%)     |             |
| Black/African-American | 38 (4.4%)  |             |
| Hispanic/Latino origin | 22 (2.6%)  |             |
| Mixed               | 38 (4.4%)     |             |
| Other               | 3 (0.4%)      |             |
| Prefer not to say   | 13 (1.5%)     |             |

**Notification:** If a user tests positive for COVID-19, they obtain a unique PIN to submit in the app. This voluntary and anonymous reporting notifies others who have downloaded the app that they may have been in close contact with someone in the last 14 days who has tested positive. PINs are typically provided to app users who receive a positive COVID-19 test by their Local Health Department (LHD).

**V. RESULTS**
A total of 1070 individuals started the survey and 1021 consented to participate (participation rate = 95.4%). After removing the responses of the participants that did not complete the survey, we had a sample of 871 completed and unique responses (completion rate = 85.3%).

**A. DEMOGRAPHICS OF THE SAMPLE**
Regarding the country of residence, 228 (26.2%) respondents indicated that they reside in the Republic of Ireland, 342 (39.3%) in the UK, and 301 (34.6%) in the US. Figure 1 shows some of the demographic characteristics of our study cohort (n = 871). The full demographic information, including the division by country, is presented in Appendix.

The majority of the participants (707/871 or 81.2%) indicated that English is their first language. Figure 1 describes the self-rated health (mental and physical) in the overall survey sample.

The majority of overall participants (818/870 or 94%) indicated that they know what is meant by contact tracing for an infectious disease like COVID-19 consistently across all three studied countries: 224/227 or 98.7% in the Republic of Ireland, 326/342 or 95.3% in the UK, and 268/301 or 89% in the US. The same applies to digital app-based contact tracing; 751/871 (86.2%) of participants knew of the existence of such technology. However, looking at the country level, the

**B. COVID-RELATED INFORMATION SOURCES AND TRUST**
Respondents indicated a strong preference (combined answers “prefer a great deal” and “a lot”) to receive COVID-related information online via either news websites/mobile apps (617/869 or 71.1%) or TV (367/866 or 42.4%). The preference to receive COVID-related news on television was particularly preferred by the UK respondents: 181/341 or 53.2% chose “prefer a great deal” and “a lot” for this information channel: 91/227 or 40.2% in the Republic of Ireland and 95/298 or 32% in the US.

The least preferred media sources were print and radio (501/865 or 58% and 382/866 or 44.2% of respondents indicated that they do not prefer to receive COVID-related news). The overall response was also negative for social media as a medium: 33.5% (290/867) of participants indicated that they do not prefer it, a trend which was more apparent in US respondents (113/299 or 37.8% do not prefer). UK respondents rated social media COVID news most favorably, only 97/341 or 28.5% do not prefer it to receive COVID-related news.

With regards to trust in COVID-19 pandemic news accuracy, public service / government ministries & departments were favorably rated by the respondents. In the overall sample, 487/867 or 56.3% of participants indicated that they trust them “a great deal” or “a lot”, detailed in Figure 2.

The least trusted groups for the COVID-19 pandemic news accuracy were religious organisations (542/866 or 62.6% have no trust at all) and social network influencers (484/867 or 55.9% have no trust at all), especially in the Republic of Ireland (146/228 or 64.1% and 156/227 or 68.5% selecting do not trust them at all respectively).

**C. DESCRIPTIVE STATISTICS ON CONTACT TRACING APPS**
The majority of the survey respondents (818/870 94%) indicated that they know what is meant by contact tracing for an infectious disease like COVID-19 consistently across all three studied countries: 224/227 or 98.7% in the Republic of Ireland, 326/342 or 95.3% in the UK, and 268/301 or 89% in the US. The same applies to digital app-based contact tracing; 751/871 (86.2%) of participants knew of the existence of such technology. However, looking at the country level, the

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4 Most of the questions did not force an answer, so a completed survey could still include unanswered questions.

5,6 One participant did not answer this question.
majority of the participants in the Republic of Ireland (96.1% or 219/228) and in the UK (94.7% or 324/342) knew about contact tracing apps, which corresponded only to 68.8% or 207/301 of participants in the US.

With regards to awareness of the availability of contact tracing apps in their country (“Do you know of any apps that help track the spread of COVID-19 in your country?”), overall, 76.8% (669/871) of respondents were aware of such apps. However, these numbers vary from country to country, which can be seen in Figure 3; The majority of respondents in the Republic of Ireland (211/228 or 92.6%) and in the UK (324/342 or 94.8%) were aware of contact-tracing apps in their country, and in the US only 134/301 (44.6%) of participants knew of such applications. As mentioned previously in Section III, at the time of the study, state-launched DCT apps were available to download in 21 out of 52 states in the US. While the majority of the US survey respondents resided in such states (248/301 or 82.4%), only half of them (124/248 or 50%) were aware of contact tracing apps being available to download in the US. As for the residents of the remaining states (53/301 or 17.6%), this number corresponded to 18.9% (10/53) of them.

The installation rate is related to app awareness, as only those who are aware of contact-tracing app availability in their country were asked whether they installed it.

We also evaluated age, gender, and education distribution for awareness of contact-tracing apps in their country and the decisions to install such apps. With regards to gender, the results for female and male participants were similar: 451/581 (77.7%) female and 201/264 (76.2%) male respondents were aware of contact tracing apps in their country. Among them, 295/450 (65.6%) females and 127/200 (63.5%) males answered that they had installed contact-tracing apps.

With regards to age, knowledge of contact-tracing apps was quite high across all age groups. This ranged from 75.5% for 41-50 year old participants to 82.2% for those over 51 years. Correspondingly, the adoption rate ranged from its highest among participants older than 51 (75.5%) and lowest for those between 31 and 40 years (57%) with the median of 64.4%.

Regarding education levels, knowledge of contact-tracing apps in their country of residence rose with participants’ education level; 49.3% of those with primary or secondary levels, 58.6% with college degrees, 81.2% with university degrees, and 86.1% with postgraduate degrees were aware of contact-tracing apps. App uptake levels did not vary greatly with the lowest rate for those with primary or secondary level of education (47.9%), and the highest for those with university degrees (62.1%).

1) ATTITUDES TOWARDS ADOPTION
With regards to the top three reasons in favor of installation of a contact tracing app, the most popular options were related to personal safety (“It would let me know my risk of being infected” 97 participants), safety of loved ones (“It would protect my family and friends” 84 participants), and “a sense of responsibility to the wider community” (64 participants).

As for the reasons against installation, the concerns most often selected were to do with surveillance by governmental authorities (“I worry the government would use this as an excuse for greater surveillance after the epidemic” 91 participants), public health authorities (“I don’t want the public health authorities to have access to my location data” 79 participants), and increased anxiety (“I don’t want to feel more anxious than I already feel” 62 participants).

In addition, thematic analysis of the responses to open questions revealed privacy issues, conspiracy theories, comments that such apps won’t work or wouldn’t have a positive effect, that they should provide some financial incentives, and general statements that participants would not install such apps (“Wild horses wouldn’t drag me to take up space on my phone for one of these”).

Participants were also asked a multiple choice question regarding the concerns they have about contact-tracing apps (if any). Those concerns often related to the exposure of their personal data to app providers (“App makers having access to your personal data”) and to the accuracy of detecting close contacts (“That the app might incorrectly state I have been exposed to COVID”). Thematic analysis of open question comments also related to doubts regarding app effectiveness due to not reaching a sufficient number of users (“Not enough people will ever have it so very ineffective”), as well as privacy, trust issues, and technical feasibility of contact-tracing apps (“Flaws in the application source code or administration of the database will lead to 3rd parties accessing my private information”).

2) APP FUNCTIONALITY
Those who indicated that they had installed a contact-tracing app were asked about their experience with it, for instance, the actions they have performed using the app. The most commonly mentioned functionality was checking COVID-related information (200 out of 426 respondents) and statistics regarding COVID cases in their region/country (183 out

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6 We did not capture the presence of other DCT efforts.
7 Due to the low number (26/871) of respondents of other genders, we do not report on differences in their responses here.
of 426 respondents), followed by logging of COVID-19 symptoms (99 out of 426).

A small number of the respondents (26 out of 426) indicated that they used the function to upload their COVID code after being tested positive. Other functions mentioned in the qualitative feedback were related to using the app to check into venues, such as restaurants or pubs, or to check the statistics of COVID cases in the region where their family members live. Several respondents reported the issues they had with the app or contact-tracing representatives, such as a failure to receive a code to upload after being tested positive, problems with the app installed on older smartphones, or never receiving any follow-ups after receiving an exposure notification.

Respondents were also asked to rate the importance of the contact-tracing app functionality. COVID exposure notification was rated as the most important feature followed by contact tracing. Symptom logging was rated as the least important feature. Figure 4 indicates the rates for each country. In addition, respondents had an opportunity to provide comments regarding this question, which was used to provide additional feedback on functionality that was not present among the question options, such as checking into venues, or logging test results and the symptoms of their family members. Another common comment was about not engaging with the app after its installation – participants expected that the app would notify them if they are a close contact of a COVID-19 case and did not interact with the app otherwise (“I have installed it, checked it works, do not check it and expect it to notify me if there is a close contact.”).

3) TRUST AND ADHERENCE

The perceived utility was measured by asking survey participants about their trust that the application accurately records close-contact events. Figure 5 illustrates the responses for each country. As can be seen, USA and Republic of Ireland respondents indicated higher levels of trust (more than 50% agree or strongly agree), this is a narrow majority, and a large proportion were less convinced across all three cohorts. Overall, the views of 58.2% survey participants ranged from “neither agreed nor disagree” to “strongly disagree,” which corresponded to 67.3% in the UK, 48.6% in the Republic of Ireland, and 49% in the USA.

The perceived effectiveness of contact tracing apps was measured by asking participants about their willingness to adhere to the instructions provided by the application in cases where the user has been identified as a close contact. As can
be seen in Figure 6, responses were generally positive. This suggests a positive intention to comply with self-quarantine instructions received through such apps.

D. STATISTICAL ANALYSIS

We present findings relative to the research questions (RQs) stated in Section II. We restate each RQ at the beginning of their respective subsection.

1) DO TRUST IN AUTHORITY GROUPS, DIRECT EXPERIENCE, AND NEWS SOURCES CORRELATE WITH APP INSTALLATION (RQ1)?

To answer RQ1, we created a Logistic Regression Model (Model 1) that included external or sociological factors that may correlate with the identified dependent variable, application installation. Resultant Odds Ratios are presented in Table 2. Model 1 investigated the correlation of respondents’ personal experience with COVID-19 (whether they are in quarantine, they or someone close to them tested or recovered from the virus, or if they belong to a high risk group), which information sources were used to get COVID-19 updates, and trust in these sources and other groups. The full model analysis is available in Appendix.

Table 2 provides the details on the statistical analysis related to Model 1. Three variables were identified as having a positive prediction effect on the odds for application installation. Each unit increment of trust in politicians in the country of residence (OR = 1.70, CI = 1.28-2.27, p < 0.001), trust in medical doctors and nurses (OR = 1.50, CI = 1.09-2.07, p = 0.01), and trust in the accuracy of the COVID-related news from political party and leaders (OR = 1.39, CI = 1.13-1.73, p = <0.001) all having a positive effect on the odds of installing a contact tracking application.

Conversely, increased levels of trust in the current government (OR = 0.67, CI = 0.52-0.86, p = 0.01) or Religious organisations (OR = 0.75, CI = 0.58-0.97, p = 0.03) leads to a decreased odds of having installed the application.

2) DO PANDEMIC RESPONSE ACTIONS CORRELATE WITH APP INSTALLATION (RQ2)?

A Logistic Regression Model (Model 2) was created to understand the impact that personal and regional perceptions of efficiency in the mitigation of COVID-19 may have on application installation. For this analysis, the following independent variables were considered:

- Respondents’ perception that their personal actions to limit the spread of coronavirus make a difference;
- Respondents’ perception that the actions the country they reside in is taking to limit the spread of coronavirus make a difference;
- Respondents’ evaluation of the official response of the country they reside in, in dealing with the pandemic.

Table 3 provides the details on the statistical analysis related to Model 2. In this Model, a statistically significant odds ratio (1.30) for installation was identified for those that
TABLE 3. Personal motivation predicting installation (Model 2).

| Source | Odds Ratio (95% CI) | Pr(>|z|) |
|--------|---------------------|---------|
| I feel that the personal actions I am taking to try to limit the spread of coronavirus make a difference | 1.17 (0.99-1.38) | 0.06 |
| I feel that the actions that the country I currently reside in is taking to limit the spread of coronavirus make a difference | 1.3 (1.11-1.53) | 0.001 |
| How effective do you think the official response has been up until now in the country you are living in, in dealing with the pandemic? | 1.12 (0.93-1.36) | 0.22 |

Null deviance: 872.67 on 666 degrees of freedom
Residual deviance: 844.77 on 663 degrees of freedom
AIC: 852.77

TABLE 4. News and information sources predicting awareness (Model 3).

| Source | Odds Ratio (95% CI) | Pr(>|z|) |
|--------|---------------------|---------|
| Online (news website or mobile app) | 0.98 (0.85-1.14) | 0.835 |
| Print (newspapers, magazines) | 0.89 (0.76-1.05) | 0.161 |
| Radio (broadcast, satellite) | 1.27 (1.09-1.48) | 0.002 |
| Social media | 1.1 (0.96-1.27) | 0.169 |
| TV (broadcast, cable) | 1.00 (0.88-1.14) | 0.976 |
| Accuracy | | |
| Friends and family | 0.98 (0.82-1.18) | 0.839 |
| Social network influencers | 0.82 (0.64-1.04) | 0.097 |
| Mainstream Media | 1.15 (0.96-1.37) | 0.131 |
| Partisan (organisation, cause, or activists related) sites | 0.97 (0.81-1.16) | 0.726 |
| Political party and leaders | 1.43 (1.17-1.77) | <0.001 |
| Religious organisations | 0.68 (0.55-0.84) | <0.001 |
| Public service / Government ministries and departments | 1.11 (0.94-1.31) | 0.236 |

Null deviance: 930.97 on 860 degrees of freedom
Residual deviance: 867.59 on 848 degrees of freedom
AIC: 893.39

3) DO NEWS SOURCES AND TRUST IN INFORMATION SOURCES CORRELATE WITH APP AWARENESS (RQ3)?

A Logistic Regression Model was created to understand whether media consumption and levels of trust in the media may affect awareness of an available COVID-19 contact-tracing application.

As detailed in Model 3 (Table 4) statistically significant odds ratios were identified for trust in the accuracy of news about the COVID-19 pandemic from religious organisations (0.68) and from political parties/leaders (1.43). Similar to the analysis presented in Table 2, but this time directed at DCT apps awareness rather than installation, this suggests that as a person’s level of trust in news from religious organisations increases, the odds of a person being aware of a COVID-19 contact-tracing application decreases. It also suggests that as the trust in news from political parties and leaders increases, so does the odds that a person is aware of a COVID-19 contact-tracing application.

4) DO DEMOGRAPHIC CHARACTERISTICS CORRELATE WITH APP INSTALLATION (RQ4)?

A Pearson’s Chi-squared test was run on participant demographics to identify associations with application installation. Participants were surveyed on gender, age, residential location (urban, rural, suburban, etc), ethnicity, language, education level, political leanings, household income level, and general health and well-being (refer to Appendix for full demographic information). CHI Squared tests were run on the entire data-set as well as on each country individually. A Bonferroni Correction [55] was applied to decrease the likelihood of False Positive results caused by performing multiple tests. This resulted in a higher threshold being used in the assessment of statistical significance for the Chi-squared tests ($\alpha = 0.00556$).

Within the demographic analysis, the strongest correlation was between installation and having English as a first language (Table 5). For the combined data-set, we identified a statistically significant ($p = 0.001313$) Chi squared of 10.324. When stratified by country the effect is statistically significant in the United Kingdom cohorts ($p = 5.962e-05$, Chi squared $= 6.6982$). With the Bonferroni Correction, this association was not statistically significant in the USA and Ireland cohorts. No other demographic parameter was identified, in this data set, as being statistically significant.

TABLE 5. Does demographic correlate with installation.

| Source | Odds Ratio (95% CI) | Pr(>|z|) |
|--------|---------------------|---------|
| Installed | English as a First Language | English as a Second Language |
| English as a First Language | 0.879 | -1.792 |
| Did Not Install | -1.166 | 2.377 |
| X-squared = 10.324, df = 1, $p = 0.001313$ |

| Source | Odds Ratio (95% CI) | Pr(>|z|) |
|--------|---------------------|---------|
| Installed | English as a First Language | English as a Second Language |
| English as a First Language | 0.918 | -2.192 |
| Did Not Install | -1.328 | 3.174 |
| X-squared = 6.6982, df = 1, $p = 0.0005962$ |

| Source | Odds Ratio (95% CI) | Pr(>|z|) |
|--------|---------------------|---------|
| Installed | English as a First Language | English as a Second Language |
| English as a First Language | 0.743 | -1.11 |
| Did Not Install | -1.347 | 2.011 |
| X-squared = 6.6982, df = 1, $p = 0.009651$ |

| Source | Odds Ratio (95% CI) | Pr(>|z|) |
|--------|---------------------|---------|
| Installed | English as a First Language | English as a Second Language |
| English as a First Language | 0.223 | -0.608 |
| Did Not Install | -0.161 | 0.454 |
| X-squared = 0.26685, df = 1, $p = 0.6068$ |
TABLE 6. Spearman’s rank correlation.

|                         | All Data | Ireland Data | England Data | USA Data |
|-------------------------|----------|--------------|--------------|----------|
|                         | rho p    | p            | rho p        | p        |
| current government      | 0.15     | 0.002        | 0.07         | 0.341    |
| politicians             | 0.09     | 0.580        | 0.08         | 0.285    |
| public health authorities| 0.21     | <0.001       | 0.23         | 0.0104   |
| medical doctors and nurses| 0.19    | <0.001       | 0.24         | 0.008    |
| scientists              | 0.25     | <0.001       | 0.28         | <0.001   |
| religious organisations | -0.04    | 0.323        | -0.16        | 0.037    |

5) DOES TRUST IN AUTHORITY GROUPS CORRELATE WITH TRUST IN APPLICATION ALERT FEATURES (RQ5)?

To assess trust in “application alert features,” participants were asked how much they agree with the statement - “If the application told me I had been in close contact with a positive COVID case I would believe it and act accordingly”. In the following questions, participants were asked about their level of trust in government entities with specific questions for level of trust in:

- The current government of the country you are living in
- Politicians in the country you are living in
- Public health authorities of the country you are living in
- Medical doctors and nurses
- Scientists
- Religious organisations

A Spearman’s rank correlation rho test was performed to see if this trust has a correlation with adherence to alerts. The threshold for statistical significance for this test is considered to be p<0.05.

As presented in Table 6, in all cohorts a weak, positive, statistically significant correlation was identified between adherence to application alerts and trust in scientists. In the combined country cohort a weak positive correlation was identified between alert adherence and trust in public health authorities. At the country cohort level, this was only seen in Ireland. In the UK cohort, a weak positive correlation was identified between alert adherence and trust in medical doctors and nurses.

VI. DISCUSSION

This cross-national study explored citizens’ acceptability of contact tracing apps, identifying that the lack of public trust in public health and governmental authorities, as well as privacy concerns, are major factors impeding adoption. In this section, we discuss these key findings in detail and provide a roadmap of suggestions for disseminating and overcoming identified barriers. We also highlight the relevance of our findings to the present state of the pandemic and point out their potential implications for crisis informatics, as well as post-pandemic public health and digital health systems.

A. AWARENESS AND ATTITUDES TOWARDS CONTACT-TRACING APPS

Our study shows that the share of participants who were aware of the nature of contact tracing was similar in all three studied countries. However, when it comes to knowledge of the digital implementation of contact tracing, the awareness was high among the UK and the Republic of Ireland residents (about 95% of the participants) and lower in the US (about 69% of the participants). Consequently, the awareness of the availability of such apps in one’s country (“Do you know of any apps that help track the spread of COVID-19 in your country?”) was much lower in the US residents compared to the UK and the Republic of Ireland, as well as the app uptake.

This finding is especially indicative considering that most of the US participants (82.4%) resided in the states where at least state-released DCT apps were available to download potentially as well as other DCT efforts; however, we did not capture their availability in this study. Nevertheless, residents of the states with state-released DCT apps available to download were more aware of DCT apps than those in the states without them, which indicates the potential effect of such official efforts and communication. The Republic of Ireland had the highest adoption rate in the sample.

Early studies conducted in these countries before nationally or state-released DCT apps became available to download identified high numbers of people willing to install such apps. The highest rates of acceptability were reported in the Republic of Ireland, which is consistent with our findings post-release. A study by O’Callaghan et al. (May 2020) indicates that 82% of their survey participants were willing to download a public health service (HSE) – endorsed COVID-19 contact tracing app [17]. A later study on the sentiment analysis of the online user feedback on the HSE Contact Tracker app after its release (August 2020) revealed positive and supportive public views, including such topics as data protection and transparency [56].
In the UK and the US, early acceptability studies also reported generally positive public views. A cross-national survey by Altmann et al. conducted in May-June 2020 showed that about 70% of respondents in the UK and 65% in the USA were willing to install contact tracing apps once they became available [11]. A social media sentiment analysis study identified overall positive sentiment toward COVID-19 contact tracing in the UK [12]. In the USA context, in a study conducted in early April 2020, Hargittai et al. explored the willingness to install a contact tracing app, and reported a positive response from 66.9% of participants [57].

While some studies indicate that initial challenges in launching contact tracing apps by the UK public health authorities hindered their uptake among the public [12], we find that views of the UK respondents in our sample are consistent with early research identifying high DCT acceptability rates. However, with regards to our US participants, they were less aware and if aware, more reluctant to install existing contact tracing apps, which differs from high acceptability rates in the hypothetical adoption scenarios [11], [57]. This finding highlights a potential misalignment between a users’ perception of technology acceptability in a hypothetical scenario and their perception when DCTs become available to adopt and use. This also suggests a potential heterogeneity of views on the pandemic and associated response strategy in the USA.

1) REASONS FOR AND AGAINST INSTALLATION
For all three countries, the most common reasons to install an app were personal safety and the safety of family and friends, as well as a sense of responsibility to a wider community. These findings are consistent with previous studies on theoretical adoption of contact-tracing apps: favourable attitudes towards such apps and sharing personal information on them is related to expected personal outcomes and the benefits for the community [17], [58], [59]. Moreover, a study by Joo and Shin showed that users who see contact tracing apps as beneficial for the public good, try to “highlight and magnify” their benefits [60]. As previous research and our findings show, it is important to highlight the personal contribution of adopting DCT and the positive impact it has on the public good but also for personal safety and the safety of loved ones.

Among the barriers to the installation of contact tracing apps, privacy concerns were the most prominent. This empirical finding is consistent both with earlier studies on privacy concerns in decisions to disclose personal information in digital and public health contexts [61], [62] and studies specific to DCT [43], [59].

Privacy decision making is often seen as a rational process of estimating the trade-off between privacy concerns and benefits of information disclosure [63], [64]. This view is consistent with previous DCT studies, as individuals are less likely to share personal information on contact tracing apps when they are concerned about information privacy [58]. However, disclosure decisions can also appear as an extreme case of the privacy paradox (the discrepancy between a users’ intentions to protect their privacy and their actual behavior) for users [65], which emphasises how important it is to consider the contextual nature of privacy decision making, especially in the crisis conditions of a global pandemic. In addition, as evaluation of privacy and security of digital health solutions can be a challenging task not only to users but even to experts [66], privacy protections in place for such apps should be visible and emphasised to mitigate associated privacy concerns. As has been noted by Hassandoust et al., stronger feeling that one’s privacy will be protected increases individuals’ trust in public health authorities being able to handle their sensitive personal data [59].

An additional, commonly identified, adoption barrier identified is additional COVID-19 anxiety associated with contact tracing app installation. While the COVID-19 pandemic is associated with negative emotions, previous research indicates that users’ mental distress can be amplified by DCT. A study by Suh and Li in South Korea revealed a negative correlation with increased negative emotions caused by DCT and the users’ intention to continue using contact-tracing apps [67]. Other studies analyzed public sentiment towards contact tracing on Twitter identifying that words associated with the emotion categories of “Anticipation”, “Fear”, and “Trust” were most prevalent [68]. DCT is part of the pandemic response and, understandably, is associated with negative emotions caused by the pandemic. Thus, the additional anxiety should be taken into consideration when designing information campaigns and addressed by the messages disseminated within the technological solutions.

2) APPLICATION FEATURES, INTERACTION, AND ADHERENCE
The majority of the study participants owned a smartphone that they keep close by most of the time and reported autonomy in installing new apps, which indicates practical potential for adoption of DCT apps in our sample. Unsurprisingly, the most important features of contact-tracing apps for participants in all three studied countries were the features related to contact tracing and exposure notification; but regularly updated information and statistics on COVID-19 cases were also identified as useful. Additionally, some participants reported low engagement with the app after installation, using the app passively as a safeguard, expecting to be notified if they come in close contact with a COVID case.

Despite doubts in the efficacy of DCT mentioned in the open comments, our survey respondents were generally willing to adhere to the instructions of a contact-tracing app if they are identified as a close contact. Individuals of different ages contribute differently to the transmission dynamics of COVID-19, and younger individuals tend to have more contacts than older adults [69]. Given the prevalence of younger people within our sample, this willingness to adhere is hence an encouraging finding.
While contact tracing accuracy concerns were also mentioned in the open comments, the overall survey responses inclined to the opinion that DCT apps record close contacts correctly. This finding is in line with the study by Joo and Shin, which showed that concerns related to input errors or incorrect results did not significantly affect factors related to user acceptability of contact-tracing apps [60].

B. PUBLIC TRUST AND ADOPTION

Based on our study results, the success of contact-tracing apps is at least partly dependent on trust in actors such as medical professionals, and politicians. This finding is in line with previous research that has repeatedly identified public trust as the critical element both in public health decision-making and for fostering the uptake of contact tracing apps [70], [71].

The acceptability and uptake of contact-tracing apps can also be dependent on trust in the accuracy of COVID-related news. Our results show that individuals who trust the information received from political parties and leaders are more likely to install a contact-tracing app. It is the opposite in the case of religious organisations: higher levels of trust in the accuracy of COVID-related news from them is associated with lower levels of contact-tracing app uptake. Information sources and views on contact-tracing apps were studied in previous DCT studies, which complement our findings. For instance, a study by Zimmermann et al. shows that the lack of transparent and consistent political communication in the Austrian context undermined public trust in authorities and had a negative effect on contact-tracing app uptake [72].

1) TRUST AND ADHERENCE

As our results show, trust can also affect the adherence to instructions provided by a contact-tracing app, such as self-isolation and testing recommendations. In all cohorts – both stratified and combined – a weak, positive, statistically significant correlation was identified between adherence to application alerts and trust in scientists.

In the combined country cohort a weak positive correlation was identified between alert adherence and trust in public health authorities. At the country cohort level, this was only seen in the Republic of Ireland. With regards to the UK cohort in particular, a weak positive correlation was identified between alert adherence and trust in medical doctors and nurses. As healthcare in the UK is mostly public, this finding could also be associated with trust in public health authorities. In contrast to the UK and Ireland, public health provision is less extensive in the US, which might also explain the lack of significant results for this region.

Trust in public health authorities could be explained with regulatory expectations associated with these institutions [59]. Nevertheless, these findings highlight the importance of fostering trust in scientists, healthcare professionals, and public health authorities for providing informed advice and promoting the adoption of public health interventions such as DCT going forward. It also shows the value of public engagement and involving these actors in the development and implementation of information campaigns. Public health authorities were often the actors responsible for releasing contact tracing apps, and previous studies recognise the importance of trust in providers for DCT uptake and data provision [73]. Such trust could be facilitated by public health authorities providing realistic information concerning public wellbeing and risk–benefit perspectives associated with contact-tracing apps [59].

Besides the implementation of DCT, the approval of other governmental actions and policies is important to consider in evaluating public trust. With clear communication that the actions the country is taking to limit the spread of coronavirus make a difference, the likelihood of installing a contact-tracing app increases.

C. DIVERSITY AND ADOPTION

While early studies predicted that only a subset of the population with certain demographic characteristics would download a contact tracing app [41], [74], our results show the uptake of such apps across demographic groups, which is consistent with previous studies on the adoption of contact-tracing apps [37] and behavioral modifications due to the pandemic [75]. While those with higher education levels might be more aware of contact-tracing apps available in their country, education, gender, and age did not greatly impact uptake rates. Our survey did not identify these demographic variables as an uptake predictor, but other studies identified that a combination of education and wealth might play a key role in CT app adoption [74], which highlights the need for further research into these issues.

All three studied countries have English as one of their official languages, released DCT apps initially in English, and the majority of our participants reported that English is their first language. Nevertheless, our results indicate that respondents not having English as their first language are less likely to install a contact-tracing app, a result which was more visible in the UK. This finding can be associated with various potential factors: one is the lack of availability of the applications in a user’s preferred language and the reduced accessibility to those whose first language is not English. Other possible causes are distrust related to DCT in minority communities [56] or immigration status and related concerns [76]. Nevertheless, this empirical finding shows the importance of addressing ethnic diversity in disseminating information and considering the risks and concerns various minority groups might associate with DCT.

D. RECOMMENDATIONS FOR POLICY AND PRACTICE

Our study results highlight the questions of trust as quite central to the adoption of contact-tracing apps across nations and demographic groups. The following are policy and design recommendations for crisis informatics and digital public health interventions such as DCT.
1) COMMUNICATION CLARITY AND TRANSPARENCY
Acceptability of crisis response public health technologies can vary before and after their release [35]. While early DCT studies show high acceptability in a hypothetical adoption scenario, our findings indicate that acceptability can change in later development stages. Hence, it is important to be transparent and consistent throughout the development lifecycle of such interventions. As for public health technologies specifically, we should consider the development of strategies for communicating their efficacy.

The actions taken to handle the crisis at a national level are important for public support of DCT. These actions should be communicated clearly, as they are essential to increase public trust and clarity in government actions and measures.

From our study, it is clear that a key policy priority should be to facilitate and support trust both in public health and governmental authorities, as they are the key providers of DCT. Public health decision-making should be transparent and clearly communicated to the public in a timely manner. The scientific community and healthcare professionals should be involved in this process, providing relevant and trustworthy informed advice on such public health interventions as DCT, in particular, tackling the spread of misinformation and distrust.

Information campaigns and using appropriate communication channels could support such efforts. Together with more traditional communication channels such as TV and radio, online information campaigns could be used more actively, especially targeting younger age groups. The inclusion of ethnic minority and English as a second language (ESL) communities should be supported by multi-language design of crisis-response technology and accessible information campaigns, and their concerns directly or indirectly related to DCT should be considered.

2) ADDRESSING PRIVACY CONCERNS
In the case of DCT, privacy concerns are a cornerstone for uptake. Such concerns might be based on previous data breach incidents or risk-benefit decision making, as well as being driven by irrational fears or misinformation. Regardless of the root cause, more attention should be directed towards ensuring that users are fully informed about current information sharing practices and security issues relating to data flows and storage, as well as the implications of sharing one’s personal information.

3) DESIGN RECOMMENDATIONS
As a crisis-response technology, DCT is associated with negative emotions caused by the crisis, which should be taken into consideration when designing messages disseminated within the technological solutions. The design of such applications should prioritize the quality of the primary functionality to minimise errors, as faults in this functionality might negatively affect its continuous use. In addition, the design should consider potential passive use and low engagement. In addition, our study identified supplemental features, such as COVID-related updates, as useful to the respondents, indicating their potential to improve engagement.

E. LIMITATIONS AND FUTURE WORK
Our study has some limitations. First, respondents recruited online may not be representative of the entire population. Online platforms and sites used to advertise the surveys are more commonly used amongst younger age groups, which likely accounts for the high number of participants in the 18–49 age range and fewer participants aged 50 and over. This is also reflected in the technology literacy of participants with only four saying they would require technical support during the act of installation. In addition, awareness and willingness to adopt technology could be higher among younger respondents.

Second, the findings are based on attitudes expressed at a specific point during the ongoing COVID-19 pandemic. A longitudinal investigation is needed to understand the impact of temporally changing factors, such as infection rates, governmental response, media coverage, or deployment, availability, and adoption of pandemic-related technologies. Longitudinal investigations can further track shifts in attitudes as the immediate disruption of the pandemic subsides. Such studies could also investigate how the acceptability of DCT apps translate to adoption, as perception does not always equate to behaviour.

As this work measured intention to use an app based on established app descriptions, future researchers could use vignettes to describe several options and their combinations, in order to assess how respondents would be willing to adopt different forms of app, depending on their specific characteristics. While it was out of the scope of this study, future research could investigate whether different providers (governmental or public health authorities, private companies, academic efforts) and information campaigns influence the awareness of such apps.

As the USA’s application rollout and adoption was managed at the state level, a state-by-state comparison could deliver clear insights into installation intentions and behaviour. The majority of USA respondents (82.1%) resided in a state that had an official application in place during the data gathering window. However, the divergent approaches that different states took to advertising and enforcement could not be controlled for within the scope of this work. The effect of those that resided in a state that did not have an official application may also affect the validity of the statistical results. In addition, future work could explore the effect of non-governmental (academic, private sector, nonprofit, etc) DCT efforts on user awareness.

VII. CONCLUSION
This cross-national study explored citizens’ acceptability of contact tracing apps, digital public health technology used to track and mitigate the spread of the virus using
massive-scale citizen data. Contact tracing apps can be used for a variety of purposes beyond immediate crisis management for COVID-19 and emerging strains. Established contact tracing applications have the advantage that they can be deployed quickly and without major modification even for new infectious diseases. High uptake is crucial for these apps to be effective in the mitigation of the virus, and the motivation and information campaigns should be appropriate to different groups (e.g. ESL).

Our results indicate that trust is a central factor for the adoption of DCT. This study shows that adoption and adherence to DCT efforts are strongly connected to the trust (or lack of it) in official actors such as public health authorities and politicians, as well as scientists and healthcare professionals. Choosing appropriate media communication channels and sources are other important factors to consider when informing citizens about existing digital crisis response solutions in order to stimulate their uptake.

With regards to interaction design, such technology might be used passively, which highlights the importance of the primary functionality not only for efficacy but also for user adoption and continuous use.

As this study shows, privacy is a cornerstone of DCT concerns. Hence, policy-makers and technology developers need to recognize that merely promising to protect individual privacy is not sufficient to ensure positive user perceptions and trust that health information they share will be protected.

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