Toward a Compare and Contrast Framework for COVID-19 Contact Tracing Mobile Applications: A Look at Usability

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Abstract: This paper reports on the progress in the project COVIGILANT, which is aimed at developing an evaluation taxonomy for Contact Tracing Applications (CTAs) for COVID-19. Specifically, this article describes the development of Usability, one pillar of the COVIGILANT taxonomy, discussing the classification and decision-making processes, and the initial model validation. The validation process was undertaken in two stages. First, we validated how the Usability pillar could be used to evaluate the Irish Health Services Executive (HSE) COVID-19 CTA. While this supported many of the attributes that we had within the Usability pillar, it also identified issues. We made amendments based on these, and undertook a second study, this time evaluating 4 CTAs used in other countries. This has led to the completion of the Usability pillar, which can now be used to evaluate global CTAs.

1 INTRODUCTION

As the novel coronavirus (Covid-19) spreads across the globe with limited treatments and no vaccine as yet discovered, governments and public health institutions look at a series of non-pharmaceutical intervention strategies to limit the spread of the virus. In this context, contact tracing (CT) is seen as a promising strategy to identify, isolate and contain outbreaks. Although traditionally a manual process, digital contract tracing applications (CTA) have been proposed to leverage the pervasive use of smartphone devices and increase the accuracy of the CT process. This paper reports on progress in the 'COVIGILANT' project, a project aimed at developing a compare and contrast evaluation framework for CTAs which would help to improve existing solutions (Buckley et al., 2020). For this purpose, the COVIGILANT project aims at better understanding the population's perception of Contact Tracing Apps (O'Callaghan et al., 2020) in the Irish context and to develop a taxonomy to compare and contrast the different aspects of contact tracing apps developed globally. The COVIGILANT taxonomy currently includes 7 pillars which were developed by the project team as aspects to be examined when evaluating CTAs using compare and contrast: Characteristics, Effectiveness, Performance, User Autonomy/Self Determination, Data Protection, Transparency and Usability. Specifically, within each pillar, there are attributes, sub-attributes and a corresponding set of questions which are posed during CTA evaluation. In this paper, we focus on the development of the Usability pillar of the COVIGILANT taxonomy. We use literature to

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develop the pillar, and illustrate its effectiveness by using it to evaluate 5 existing CTAs which are being used in different countries.

The first section provides a definition of COVID-19 CTAs, their types, the international regulations for their development and design, and limitations found in the existing frameworks. The second section reports on the development of the COVIGILANT taxonomy, specifically its Usability pillar and the structure of the attributes within. This section also explains how we tested, reviewed and refined our first iteration of the Usability pillar. The paper concludes with a summary of the findings and outlines plans for future work.

2 CTA FOR COVID-19: DEFINITION, TYPES, EU REGULATIONS AND AVAILABLE FRAMEWORKS

Paper-based CT strategies have existed through previous pandemics (Swanson et al., 2018). However, these are intense and require tedious manual entry which is prone to human error. The use of technology for tracing activity has shown promising results in the monitoring process of Ebola (Danquah et al., 2019) and has generated understandable enthusiasm as a means to prevent the further spread of COVID-19 (Goggin, 2020). In this section, we first provide a definition of CTAs and their various types as they are discussed in the growing academic literature on this subject. We outline some of the regulations and principles suggested for their design, discussing existing frameworks offered for evaluating CTAs.

2.1 Definitions and Different Types of CTAs

CTAs are mobile applications that are developed for and used in smartphone technology. According to the World Health Organisation (WHO) (2020), these applications are "also known as proximity tracking tools", that "use location-based (GPS) or Bluetooth technology to find and trace the movements of individuals to identify people who may have been exposed to an infected person". Different types of CTA are being developed. These use different approaches to contact tracing and different approaches to data storage, management and usage. To help classify these approaches, the WHO (2020) considered two main forms of CTAs: a) centralised form where the processing of the contact history data is central, usually undertaken by health authorities and b) decentralised where the data is kept in the users' devices. In both cases, GPS or Bluetooth technologies are used to collect data and include alert notification functions to warn users of a potentially infectious exposure.

2.2 EU Regulations for the Development and Design of CTAs

To develop effective app solutions, a series of design requirements were proposed by the European Commission to ensure that the use of the digital tool:

a) will address accessibility and inclusiveness and be on a voluntary basis,
b) be approved by the national health authority to be monitored, and
c) will include forms of encryption for preserving personal data.

Additionally, once the pandemic is over, the app can be deactivated and disassembled (eHealth Network, 2020).

Similarly, the Information Commissioner's Office (ICO) (2020) published ten core principles[1] to follow when designing CTAs. These have been grouped to cover the application development life cycle. Some of these principles discuss the importance of building "core requirements" which include "user experience (UX) design and other appropriate in-app transparency mechanisms", and that they "should adopt a user centric design approach" (ICO, 2020). However, despite all these regulations, requirements and principles, the CTAs will be effective only if they are integrated into the "existing public health system" and adopted by the majority of the population (WHO, 2020).

2.3 Existing Frameworks for CTAs and Their Limitations

Our first steps were to look at the available academic and grey publications discussing evaluation frameworks for CTAs. A Cho et al. (2020) and De Carli et al. (2020) offer two frameworks which

[1] Transparency about the purpose, transparency about the design choices, transparency about the benefits of using the application, minimum amount of personal data collection, protect users by using pseudonymous identifiers, ensure users have control over the app, store collected data for a minimum amount of time as users have control over it, encryption of data, voluntary participation and ensure privacy and security.

primarily focus on privacy issues. Gasser et al. (2020) propose a framework whose scope is the ethical and legal challenges of CTAs, while Dar et al. (2020) look mainly at feasibility and effectiveness aspects. Despite certain differences, these frameworks commonly highlight the specific importance of privacy and data protection in CTAs, and this led us to acknowledge that we need a specific pillar about this aspect in our taxonomy. Only the assessment framework for mobile and web-based applications developed for COVID-19 suggested by Vokinger et al. (2020) includes usability aspects. Vokinger et al.'s framework is based on "an existing trustworthiness checklist for digital health applications" and comprises eight domains (i.e., Purpose, Usability, Information Accuracy, Transparency, Organisational Attributes/Reputation, Privacy and User Control/Self-Determination) (2020). The authors, however, also highlighted the following limitations:

1) The framework was specifically designed to the Swiss privacy law aspects which stress transparency and user privacy but limits it to the Swiss context, and
2) Usability criteria and technical characteristics of CTAs are included but not developed sufficiently.

We have identified this as a research gap, and our research question for this paper is:

How can Usability attributes be integrated into a taxonomy through which CTAs can be compared, contrasted and possibly improved?

3 RESEARCH METHOD: CREATING AND ASSESSING USABILITY PILLAR FOR CTA

To address the limited scope of the CTA frameworks we initially reviewed with respect to Usability, and to further develop a Usability pillar, three researchers assessed three further types of literature in detail. First, we looked at the most recent guidelines for mobile apps (Alturki & Gay, 2019; Goel et al., 2018; Shitkova et al., 2015; Weichbroth, 2020), and specifically for mobile health apps (e.g., mHealth) (Kasali et al., 2019; Kaur & Haghighi, 2016; Xcertia, 2019). This literature is important because it overviews a number of Usability attributes and guidelines. For instance, 75 attributes for the Usability of mobile applications were distinguished and analysed through a systematic literature review by using only the Scopus database (Weichbroth, 2020). The article discussed only the attributes that appeared more than once (N=24). Xcertia (2019) provides guidelines on five key areas of Privacy, Security, Usability, Operability and Content to ensure that mobile health apps cover the needs of clinicians and end-users. We also searched more traditional literature on Usability including: the Usability standards ISO 9241-11, Nielsen Usability framework (Nielsen, 1993), Preece et al. (2015) Usability taxonomy (1998/2019) and notions from Norman's psychology (Norman, 2013) of everyday objects (1998/2012, e.g., Affordances, Constraints and Mapping). This literature gave us a rich range of notions to focus on for the development of a Usability pillar (e.g., User Satisfaction is found in all mentioned frameworks, Efficiency and Learnability are mentioned on most of them). Eventually, we also acknowledged the key importance of Accessibility which is often included as an aspect of Usability and which led us to further review the literature and standards on Accessibility (Ballantyne et al., 2018; ETSI, 2018; EU, 2016) and Universal Design (UD) of mHealth apps (Harrington et al., 2017; Kascak et al., 2014). That literature includes design requirements for users with various type of impairments (e.g., visual, motor, cognitive), but also 'special' categories of users such as the elderly. This initial review helped us to identify an initial list of 53 attributes relevant to CTA, and Table 1 shows all the used sources (first column) and attributes (second column).

The initial list of attributes was discussed by a subset of the COVIGILANT team (8 researchers), and against the 7 initial pillars for the COVIGILANT taxonomy: Characteristics, Usability, Effectiveness, Performance, User Autonomy/Self Determination, Data Protection and Transparency. We acknowledge that some issues (which in a different context could be treated under Usability) deserved a more specific focus in CTAs. Based on this consideration, aspects such as Effectiveness, Performance, User Autonomy and Transparency were developed as pillars on their own, independent from the Usability group, by other members of the team. In line with existing CTA frameworks, Privacy and Data Protection were also treated independently.

Seven of the discussed attributes were specific to Usability and were used as starting points for the development of the Usability pillar (version 1.0) (Figure 1). These were:

1) **Subjective Satisfaction:** "refers to how pleasant it is to use the system" (Nielsen, 2009);
2) **Availability (New):** inequalities in the access based on internet connectivity and platform dependency;

Table 1: An overview of the most relevant attributes identified in academic publications.

Frameworks	Proposed attributes
Contact tracing apps for COVID-19 (Vokinger et al., 2020)	Purpose, Usability, Information Accuracy, Organisational Attributes /Reputation, Transparency, Privacy, User Control/Self-Determination
mHealth (Kasali et al., 2019; Kaur & Haghighi, 2016; Xcertia, 2019)	Efficiency, **Satisfaction**, **Effectiveness**, Learnability, Memorability, Cognitive Load, Simplicity, ***Universality***, Aesthetics, Security, Usefulness, Resources, Troubleshooting, **Ongoing App Evaluation**, Name of the Application
UD for mHealth apps for older individuals (Harrington et al., 2017; Kascak et al., 2014)	Navigation, Affordances, **Interaction**, Equitable Use, **Flexibility**, Ease of Use, Errors, Low Physical Effort, Size and Space for Approach and Use
Accessibility (Ballantyne et al., 2018)	Perceivable, Operability, Understandability, Robustness, Design, System, Content
Mobile applications (Alturki & Gay, 2019; Goel et al., 2018; Shitkova et al., 2015; Weichbroth, 2020)	Attractiveness, Comprehensibility, **Accessibility**, Consistency, Training, Trust, Battery Consumption, Less Storage Consumption, Adaptability, Performance, Layout, Platform Dependency, Onboarding, Speed, ISO 9241-11 (Efficiency, Satisfaction and Effectiveness)

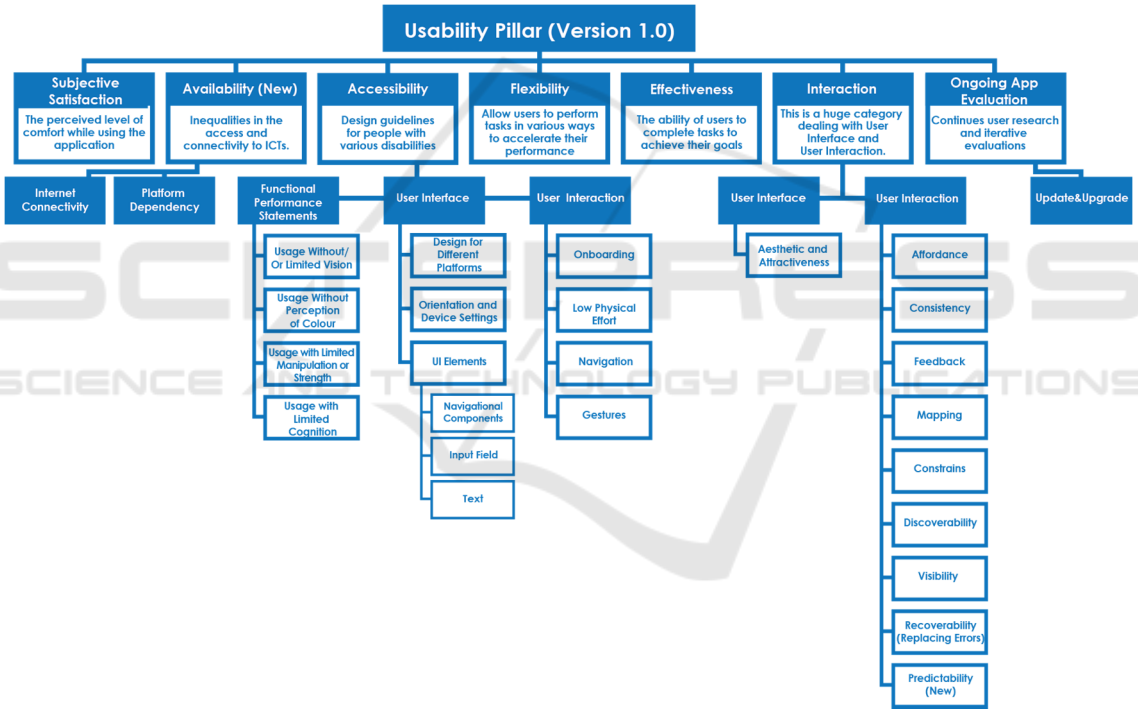

Figure 1: Visualisation of the initial structure of the Usability pillar (version 1.0).

3) **Accessibility:** design guidelines for individuals with cognitive, visual, hearing and dysmotility;
4) **Flexibility:** allow users to perform tasks in various ways to accelerate their performance;
5) **Effectiveness:** the ability of a user to complete a task to achieve their goals;
6) **Interaction:** design of the User Interface (UI) and user interactions;
7) **Ongoing App Evaluation:** presence of user research and iterative evaluations after the app was released.

We included Accessibility under Usability. Furthermore, we found that Platform Dependency and Internet Connectivity are also elements of Accessibility to be accounted for as CTAs might not work in all smartphones and typically require an active connection to be installed during setup. To accommodate this, we included an 'Availability' category under Accessibility. Satisfaction was changed to 'Subjective Satisfaction' adhering to Nielsen's definition (2009).

After identifying these seven high-level dimensions, our job was to again review the literature, so that we could populate these high-level categories with attributes, sub-attributes and specific questions to be asked when using our Usability pillar to assess existing CTAs. For each attribute and sub-attribute, a definition was given (based on that literature) and at least one probing question (also based on literature when this is available, or freely formulated by us otherwise). We included a commentary on the feasibility of such questions, detailing how one could possibly answer them (e.g., the Devil's Advocate approach). This ensured that, not only had we identified probing questions, but they could be answered. This resulted in the top seven attributes being expanded into specific sub-attributes with 77 related questions. A subset of our results is shown in Table 1. To validate the Usability pillar, we tested initial list of questions by applying them to the Irish Health Services Executive (HSE) 'COVID Tracker'[2] contact tracing app.

3.1 First Assessment of Usability Pillar: HSE App Assessment

Our initial draft on the Usability pillar was tested with the Irish HSE app, and a series of issues both in the structure and in the questions were immediately apparent:

1. The usability structure looked quite unbalanced and disproportionate as:
   a) two attributes had many sub-attributes (i.e., Accessibility and Interaction)
   b) three attributes had no sub-attributes (i.e., Flexibility, Effectiveness and Subjective Satisfaction)
   c) some of the attributes (i.e., Accessibility and Interaction) had sub-attributes with the same labels (i.e., User Interaction and User Interface)
2. A few of the attributes were found too broad as:
   a) Effectiveness is discussed in two places; as a pillar of the COVIGILANT taxonomy, and as one of the attributes in the Usability pillar
   b) Accessibility included three sub-attributes (i.e., Functional Performance Statements, User Interface and User Interaction)
   c) Subjective Satisfaction was found to be too subjective; it required better-formulated questions
3. Many of the attributes and their subsequent questions helped to identify more than one issue, indicating:
   a) wrong positions of the attributes (i.e., Accessibility and Flexibility) and/or questions (i.e., needed to relocate the question in the sub-attribute Low Physical Effort)
   b) not well-formulated questions (i.e., question used for the sub-attribute User Interaction)
4. Most of the questions were developed for the Interaction attribute. This provoked further discussions on criteria for inclusion and exclusion based on the assessment approach (e.g., heuristic evaluation, should some attribute in Usability be task-based rather than general about the whole CTA?)

Table 2 presents a short summary of the issues found with the appropriate solutions.

To achieve a more balanced structure on Usability (version 2.0), we address the issues uncovered by testing version 1.0 with the Irish HSE app (Table 2), but we also refined the taxonomy based on the work of Alonso-Ríos et al. (2010). We found this work to be very helpful. Their work overviews and compares existing Usability taxonomies towards an integrative framework offering an exhaustive description and definition of Usability attributes. It offered the opportunity to clarify our terminology (e.g., the difference between clarity and consistency) and to expand and rearrange our categories to develop a hierarchical structure of Usability, removing redundancy and repetitions. We made several changes in the Usability structure and questions:

1. 'Effectiveness' and 'Interaction' attributes were re-labelled respectively into Design Effectiveness and User Interaction (Tasks Specific). Each of these attributes has four sub-attributes. For the former, these attributes are covering the capacity of the system, interface, and interaction design (i.e., Completeness, Configurability, User Interface and Helpfulness). For the latter, they are looking at the interaction with the app UI in performing a particular task (i.e., Efficiency, Robustness, Clarity of Interaction with Elements and Consistency of Interaction with Elements).
2. We created two new sub-attributes for Subjective Satisfaction (i.e., Motivations for High Score and Motivations for Low Score).
3. Universality is a new attribute; it refers to the ability of the app to be used by different users (different because of impairments or culture); it has two sub-attributes Accessibility and Cultural Universality.
4. Questions were further refined in a bottom-up fashion. This approach helped to identify a limited number of specific questions related to the

[2] https://covidtracker.gov.ie/

attributes which were more effective for doing a CTA review.

We undertook a second validation phase, using the Usability pillar again to evaluate 4 further CTAs more specifically (e.g., individual questions picked up unique CTA issues), and categories and definitions were clearer.

3.2 Four CTAs Assessments: Results and Amendments to the Usability Pillar

We identified four CTAs[3] with different characteristics and used the Usability version 2.0 against them. These CTAs were developed for health authorities and users in EU and non-EU countries. They were selected on the basis that they had different characteristics, for example, content, user interface design and navigational elements. This variety allowed us to test the Usability pillar structure and questions to detect where improvements are possible or needed. We found these activities very useful in two ways. First, it particularly helped to add/improve some of the questions we had under Accessibility (i.e., for the input fields and activation of accessibility technologies in the device settings) and it helped in the Universality attribute for the Language subsection. Second, it helped to identify new sub-attributes to be added to the pillar such as Notifications, Content and Age/Parental Control (Figure 2).

Table 2: Examples of issues identified in the usability structure and questions (version 1.0) along with the appropriate solutions.

Attribute/ Sub-attributes/Questions	Refinement issues	Solutions
Attribute: Effectiveness	a) Use the same label with a pillar examining the effectiveness of contact tracing function b) Does not include sub-attributes	a) Re-label as a Design Effectiveness b) Create four sub-attributes, i.e., Completeness, Configurability, User Interface and Helpfulness.
Attribute: Accessibility	a) Clashing with Universality b) Includes many sub-attributes (i.e., Functional Performance Statements, User Interface and User Interaction) overlapping with more traditional Usability issues	a) Create a new attribute Universality with two sub-attributes, i.e., Accessibility and Cultural Universality b) Create three sub-attributes for Accessibility, i.e., Functional Performance, UI Elements, Accessible Interactions
Attribute: Interaction	a) Include most of the questions developed for the Usability pillar b) Refers to the actual interaction with an interface in the execution of specific tasks	a) Re-label as User Interaction (Tasks Specific) b) Create four sub-attributes, i.e., Efficiency, Robustness, Clarity of Interaction with Elements and Consistency of Interaction with Elements
Sub-attribute: User Interaction	a) Appears in two attributes, i.e., Accessibility and Interaction b) Refers to the actual interaction with an interface in the execution of specific tasks	a) Create only one main attribute, i.e., User Interaction (Tasks Specific) that includes four sub-attributes, i.e., Efficiency, Robustness, Clarity of Interaction with Elements and Consistency of Interaction with Elements
Sub-attribute: User Interface	a) Appears in two attributes, i.e., Accessibility and Interaction b) Refers to the User Interface elements and how accessible they are designed	a) Re-label as UI Elements b) Relocate the sub-attribute in the attribute Universality, sub-attribute Accessibility
Question: Q1: Is multimodality offered?	a) Question assesses more than one issue, i.e., Accessibility and User Interaction b) Current position - in the attribute Interaction, sub-attribute User Interaction c) Refers to the multiple modes available for interaction, i.e., Flexibility/Multimodality	a) Create a new sub-attribute with a label, i.e., Flexibility/Multimodality, attribute User Interaction (Tasks Specific) b) Relocate the question in the sub-attribute Flexibility/Multimodality, c) Formulate a better question, i.e., Q1: Can the same tasks be executed in different ways?
Question: Q1: Can a user complete a task without scrolling?	a) Current position - in the sub-attribute Navigation, attribute Accessibility b) Refers to the reduction in physical effort, i.e., sub-attribute Low Physical Effort	a) Relocate the question in the sub-attribute Low Physical Effort, sub-attributes Accessibility and Accessible Interactions

[3] AMAN https://amanapp.jo/en
Corona-Warn-App https://www.coronawarn.app/en/
NOVID https://www.novid.org/
PathCheck SafePlaces https://pathcheck.org/

Figure 2: Visualisation of the final Usability pillar (version 2.0) after application to the four CTAs.

For example, to support individuals who have various limitations and disabilities, some of the CTAs use various options for the input fields used for self-reporting of a positive COVID-19 diagnosis, e.g., manually entering the data, voice control and QR code. Likewise, promoting accessibility, it was found that all apps support more than one spoken language where selection was either in the app during the activation process, in the app settings or in the device system when picking up the preferred language. Questions were improved to cover and assess the availability of such options in the apps. In addition, a few questions were added to assess whether the app design accommodates the OS-level changes from the device settings (e.g., font, colour and contrast) and the accessibility features after they are activated from the device settings (e.g., screen readers). We also acknowledge age restriction as an important aspect of CTAs. Only the Irish HSE app offers age restrictions during the activation process, the other CTAs we analysed describe these restrictions in the section 'Terms of Use'. To frame this aspect, we followed the guidelines for inclusiveness (eHealth Network, 2020), and we added a new subgroup 'Age/Parental control'.

The implementation of these amendments brought us to finalise version 2.0 of our Usability pillar, which we will continue to assess both internally, by addressing redundancies and relocation of attributes within the 7 pillars, and externally, by continuing to test the Usability structure and questions with real CTAs to stress its scope and limitation.

4 USABILITY PILLAR: FUTURE WORK

We presented the research question: How can Usability attributes be integrated into a taxonomy through which CTAs can be compared, contrasted and possibly improved? Our approach was to draw on different sources for design requirements (health apps, mobile apps, accessibility guidelines (noting particularly the elderly who are an at-risk category for COVID-19)). This top-down approach, drawing on existing literature and helping us to identify 53 initial attributes, was complemented with bottom-up, iterative-refinement of Usability version 1.0. Through an initial test using the Irish HSE COVID-19 CTA, we identified both the questions that worked and the limitations in the initial structure and questions. We undertook further exploration of available literature, expanding beyond healthcare, and proposed a more balanced structure by adding new attributes and formulating task-specific questions up to a refined version 2.0 of our Usability pillar. The same strategy was applied to the other 6 pillars (see Welsh et al., 2020, for work on Data Protection pillar) included in the COVIGILANT taxonomy. The next planned activities are focused on an amalgamation of all pillars, the assessment of the full set of questions again in order to propose a refined evaluation framework that can effectively evaluate various types of CTAs. We are considering how different questions might concern and be relevant for different stakeholders in the CTAs ecology, for example, developers, Health Departments, data protection authorities. We are exploring how different 'vistas' could be created to align with the different concerns of different stakeholders, thus offering a tailored subset of pertinent questions to understand where CTAs could be improved.

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