Contribution of Medical Informatics to Battling Covid-19

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Editorial to the special issue „Contribution of Medical Informatics to Battling Covid-19"

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The Covid-19 pandemic has changed daily and academic lives, threatening the health and economic situation worldwide. Extensive research has led to insights in understanding the spread of the disease and in the development of new vaccines. A variety of disciplines have contributed to support the management of the disease for prevention, diagnosis, and therapy of Covid-19 as well as the control of the pandemic.
The role of epidemiology and infectiology is obvious in pandemic control. Additionally, various other disciplines, medical and non-medical alike, have to work together to adequately cope with the urgent needs arising from such an exceptional situation. Medical Informatics is the science of the systematic indexing, representation, management, storage, processing, and provision of data, algorithms, information, and knowledge in medicine and healthcare. Therefore, it bridges medical advances with progress in information technology in order to design the best possible health care, and is therewith playing a pivoting role in the battle against the COVID-19 pandemic and its far-reaching consequences in most facets of our lives.

In this spirit, we invited the students of our Medical Informatics Master program to prepare manuscripts for a special issue on the state of the art and the variety of medical informatics research and achievements to manage the current Covid-19 pandemic. The work was conducted as part of a mandatory curricular course, starting with a creativity workshop on the challenges of handling the pandemic and the potential of Medical Informatics within this context. Afterwards, the students identified research questions from these topics, on which they followed up in the winter term 2020/21. They conducted systematic literature reviews or meta-analyses, and the manuscripts underwent a peer review process from their fellow students. The resulting articles are published in this special issue.

The special issue kicks off with a technology that is on the rise in various nations worldwide to trace and contain the outbreak of the virus. **Finsterle, Graf, & Lingg** provide an overview and assessment of different technical approaches to implement contact tracing apps and their utilization in a selection of European countries. In order to support the diagnosis of COVID-19, several approaches for deep-learning based classification of X-ray and CT images are currently developed. **Bessaheken, Mobinzada, & Zhao** present the results of a meta-analysis on the performance of algorithms for this use case.

The remaining articles in this special issue focus on telehealth. In order to reduce the spread of the virus, the impact and penetration rate of telemedical interventions grew during the pandemic. Many countries have taken measures to enable continuous medical care in times of physical distancing. **Bleher, Goos, & King** gathered societal and technical conditions for developing telehealth services and compare the progress in implementing these services in several European countries on the backdrop of these conditions. **Elias, Gordejeva, Hensel, & Schorsch** complement this work by providing an overview about the impact of telemedical interventions on from the perspectives of physicians' work and patients' welfare. **Buchweitz, Hoffmann, & Wedel** focus on specific teletherapies for children with mental health issues who are either in need for continued treatment in spite of physical distance, or negatively affected by the pandemic situation and therefore in need for therapy. A mental problem that arose specifically for elderly populations was social isolation. **Ballarin, Minor, & Ross** provide an overview about the potential of telecommunication and of social robots in order to compensate for the lack of physical human contact. A common technique for the general population to compensate for the decrease of direct social contact is social media, whose usage increased considerable during the pandemic. The final article in this special issue from **Jung, Le, & Rau** reviewed the positive and negative effects of social media on mental health that are especially apparent during the Covid-19 pandemic.

Comparison of selected Covid-19 contact tracing apps: Functionality, privacy, effectiveness and acceptance in society

A. Finsterle, M. Graf, M. Lingg

Abstract— **Contact tracing is one of the most effective measures to contain the Covid-19 pandemic. Many countries have developed contact tracing apps to support the manual process. The apps should, if possible, track all persons with whom an infected person has had contact. This paper compares different technologies of contact tracing apps. These are considered from the point of view of functionality, data protection and their effectiveness and acceptance in the population.**

It was possible to show the most important basic technologies of contact tracing, and it was also possible to show that data protection has a high priority in the countries studied, whereas the acceptance of the contact tracing app is below. It was shown that the effectiveness can be strongly dependent on the number of users.

Future research must show why the acceptance in the countries is low. In addition, the contact tracing apps must be tested for their effectiveness with the help of real figures.

Index Terms— **COVID-19, app, contact tracing, SARS-CoV-2**

I. Introduction

THE Covid-19 pandemic is the biggest global crisis in decades. Covid-19 is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This highly infectious virus can cause respiratory diseases with a mild to fatal course. Due to a high number of acute, severe courses, many countries run the risk of overloading their health care systems [1, 2]. To contain the spread of the virus and relieve the burden on the health care system, many governments have imposed regional or even national lockdowns, as well as other restrictions on public life. In order to avoid further lockdowns, it is essential to interrupt infection chains at an early stage and to trace them. Contact tracing of infected and potentially infected persons plays a major role in this process. The aim is to identify persons who have been in contact with infected persons and to take appropriate measures. Thus, it is possible to send only individuals into quarantine instead of imposing large-scale lockdowns.

The development of contact tracing apps is intended to identify possibly infected persons. The apps support contact tracing by automatically saving all contacts of all people with apps. This has the advantage that contact tracing does not depend solely on the memory of the infected person. It may be that people do not remember all contacts of the last weeks. Furthermore, it is not always possible to know all persons by name. This is especially the case in public life, for example when using public transport or in supermarkets. With an app, these contacts can also be completely recorded.

During the pandemic, many countries have already developed different contact tracing apps. This review compares different types of apps in terms of functionality, privacy, effectiveness and acceptance.

II. Methods

For the categories functionality and data protection, a non-systematic literature search was conducted. For the category acceptance and effectiveness, a systematic literature search was performed.

A. Non-systematic literature research

A non-systematic literature search was carried out when creating the research question. Three basic technologies Bluetooth, Global Positioning System (GPS) and Quick Response-Code (QR-Code) were identified. Some contact tracing apps use mixed forms of these technologies. In this paper, only apps that use only one of these technologies are considered. In addition, only official government apps are considered.

The German "Corona Warn App" (CWA) is used as an example of Bluetooth technology. On the one hand, it is considered a pioneer in terms of data protection, and on the other hand, the documentation of this app is very extensive. All states of the European Union (EU) that are developing or have developed an app were guided by the concept of the German Corona Warn app. During the research, it turned out that France was the only EU country using a different concept regarding storage. Therefore, it is additionally taken up as an example in chapter 3.2.

For the GPS technology, the Icelandic app was chosen because most of the information being investigated could be found. Moreover, this app is the only European contact tracing app using this technology.

There is no QR-Code-based app in Europe. Only the New Zealand app could be found for this technology. At the time of the research, this is the only app that only uses QR-Code technology worldwide. Many only use the QR-Code technology as an add-on.

The information about the apps and their privacy policies was collected via the apps' official websites and privacy statements. In order to get a better overview of the complete range of functions of the EU apps, all apps available in the Google Play Store were also downloaded and analysed. Out of 19 currently running EU apps, the apps from Malta and Croatia could not be found in the Google Play Store. The Hungarian app can only be activated with a Hungarian cell phone number and was therefore also excluded from the search. Hence 16 apps were included in the analysis. Those were the apps from Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Slovenia and Spain.

B. Systematic literature search

Subsequently, a systematic literature search was conducted. This was mainly used for the chapter on acceptance and effectiveness. For the literature research the scientific search engines PubMed and Google Scholar were used. For PubMed the search string "((Covid-19) AND (Contact Tracing) AND (App))" was developed. This search gave 47 results on 09.11.2020. For Google Scholar the search string "Covid-19 AND Contact Tracing AND Apps" was used and the results were sorted by relevance. A total of 4.110 articles was delivered on 09.11.2020. As this number was too large to review all articles, it was limited to the first three pages and thus to 30 scientific articles. A total of 77 documents from both search engines were included in the further literature research. After removing duplicates, the number was reduced to 69 papers. The papers were examined regarding the category acceptance and effectiveness. If a paper dealt also with one of the other categories like functionality or privacy it was also considered. The abstracts of all documents found were read and if a paper matched at least one of these categories, it was retained. 18 papers were removed, and 51 papers remained. Only a few of the 51 papers dealt with the previously defined countries or provided general information about the categories. Therefore final 11 papers were cited. This information is summarised in figure 1.

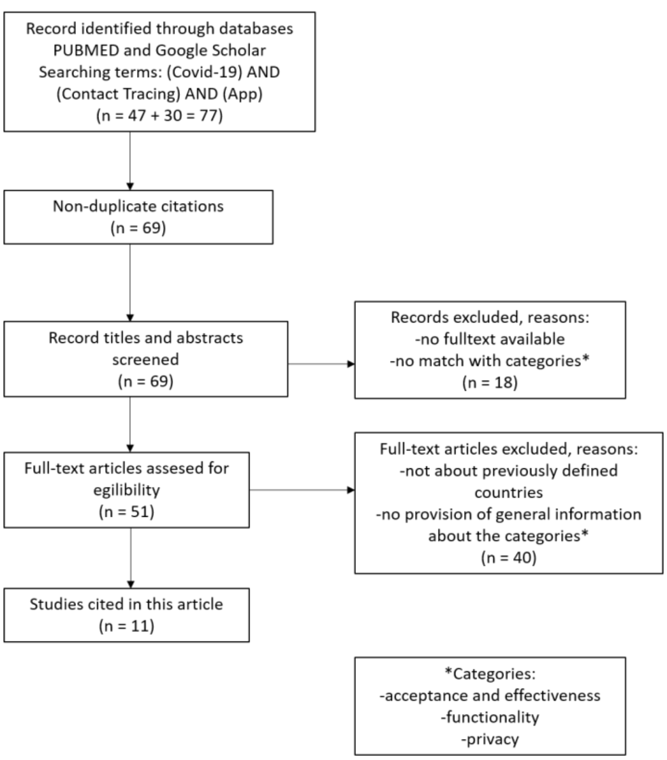

Fig. 1 PRISMA diagram

III. Result

The paper deals mainly with the contact tracing apps of Germany, New Zealand and Iceland. The German "Corona Warn App" was published on 16 June 2020 and downloaded 22.8 million times by 19 November 2020 [3, 4]. This corresponds to about 27 percent of the German population [5]. The CWA was published by the Robert Koch Institute for the German government [6]. The app was mainly developed by the German companies SAP and Telekom [7].

The New Zealand "NZ COVID Tracer" app was released on 20.05.2020 and downloaded 2.379.900 times until 24.11.2020, which corresponds to about 47 percent of the population [8–10]. The app was developed by the Ministry of Health of New Zealand [11].

The Icelandic "Rakning C-19" app was released on April 2, 2020 and according to the government, 40 percent of the population downloaded the app [12, 13]. This corresponds to about 147.000 downloads [14]. The app was published by the Directorate of Health and the Department of Civil Protection and Emergency Management [13].

These apps are available from the App Store and Google Play Store.

A. Functionality

There are currently 3 different basic types of Covid-19 tracing apps on the market, as well as mixed forms. Besides apps that work with Bluetooth, there are apps that track the location via GPS or apps that require scanning QR-Codes at all places you enter. The majority of the apps currently available worldwide use Bluetooth technology for distance measurement. In the EU, all 19 countries that have developed an app so far used Bluetooth technology.

1) Bluetooth-App

The CWA will be presented as a representative of the Bluetooth apps. The developers used the Bluetooth interface from Google and Apple for the implementation. With the help of the Bluetooth LE (BLE) technology smartphones can detect other devices that have this app installed and are in the vicinity. BLE is a special mode of Bluetooth technology, which is energy-saving and available in most smartphones [15].

All encounters with other smartphones are being tracked and the smartphones exchange random codes [16]. There are two different types of random codes. On the one hand there are daily codes, which are renewed every 24 hours. On the other

hand, there are Bluetooth-IDs, which are derived from the daily key and are changed every ten to fifteen minutes [17]. Additionally, to just noticing encounters a smartphone can receive the Received Signal Strength Indicator (RSSI) of an incoming signal from the other smartphone. From the value of the RSSI the distance between the sending and receiving device can be approximated [18]. The time of the encounter and the distance of the smartphones is also part of the exchanged codes.
It is furthermore possible for a person who gets tested to link their test with their CWA. A QR-Code is printed on the entry form for the laboratory sample of a Covid-19 test if the laboratories can technically carry this out. The patient receives this code via email with the possibility to register their test in the app. As soon as the test result is available, it is automatically displayed in the app, which can be seen in figure 2. In addition, the test result is sent by email to the person who has been tested, which is also the procedure for people who decide to not connect their test with the app.
The user can then decide whether he wants to share the information of a positive outcome in order to warn his contacts. If the laboratory is not yet connected to the infrastructure of the CWA, a positive test can also be confirmed via tele TAN in the app. The teleTAN can be requested via a service hotline [19].
After consent to share the positive test result, the own daily keys of the past 14 days are transferred to a server. On the following day, the current daily key will also be forwarded. The transferred daily keys are made available to all app users. On your own smartphone, the system automatically checks whether you have had an encounter with a person who was tested positive. This check takes place once a day [19]. Afterwards an overall risk calculation follows. The transmitted positive identifications are compared with the Bluetooth IDs stored on the own smartphone, if matches are found, a risk score is calculated. The score includes the risk of transmission, the number of days since the encounter, the duration of the encounter and the attenuation value of the Bluetooth signal [17]. For example, if encounters lasted less than ten minutes,

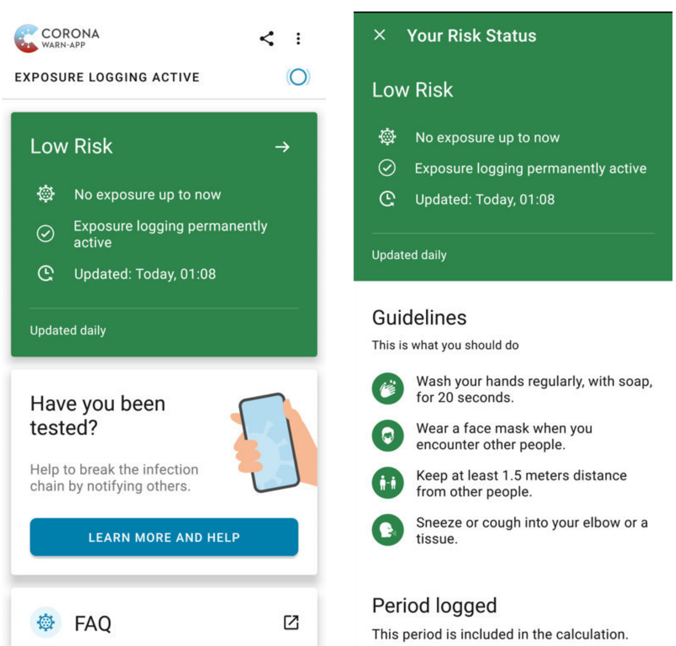

Fig. 2 Main page of CWA (l); Details on risk status (r)

regardless of distance, or the smartphones were more than eight meters apart, regardless the duration of time, the encounter is considered harmless does not count towards the score. The remaining encounters are evaluated according to further criteria regarding distance and duration [16]. The app shows the user how high the risk of infection is currently estimated, which can be seen in figure 2.
Three different risk statuses were developed for this purpose.

1. Low risk
   This status is displayed if no encounter with a demonstrably infected person has yet taken place, or if the duration and interval of the encounter has not exceeded the defined threshold value. In addition to the status, the user is provided with information on general distance regulations and hygiene recommendations, which is also displayed in figure 2 [19].

2. Increased risk
   If within the last 14 days there has been an encounter with at least one person tested positive for Covid-19, in which the threshold values were exceeded, the status “increased risk” is displayed. The app also shows when the last risk encounter took place. The user is given further behavioral advice. For example, he should stay at home, contact his family doctor, on-call service or the public health department in order to coordinate further action with them [19].

3. Unknown risk
   This status is only displayed if the risk determination has not been activated long enough [19]. A risk determination is possible at the latest 24 hours after installation of the app. After that, the indication changes to one of the previously mentioned risk statuses [7].

2) GPS-App

Tracing with the Icelandic tracing app “Rakning C-19” is done by analyzing GPS data. The location data is stored on the user's smartphone and not on a server. The app runs in the background of the smartphone and saves the location several times per hour. Data is only saved for 14 days and deleted afterwards [13].

When a Covid-19 test is performed, the person to be tested has to provide information about their phone number and their national ID number. If the test result is negative, the user is informed via app, text message or mail. If a diagnosis is made with Covid-19, the user instead is contacted by a tracing team via phone call. The tracer also sends a request to the app of the positive tested user, if the infected person uses “Rakning C-19” on their phone, to share their GPS data with the Ministry of Health. A new area appears in the app for that purpose. After confirmation of the identity the localization data will be transmitted afterwards. The team then uses this data, as well as the conversation with the infected person, to identify possible other infected individuals and exposed places [13].
In contrast to the German app, Icelandic users are not shown a risk status. Instead, current information about Covid-19 infections in the country as well as information for tourists is

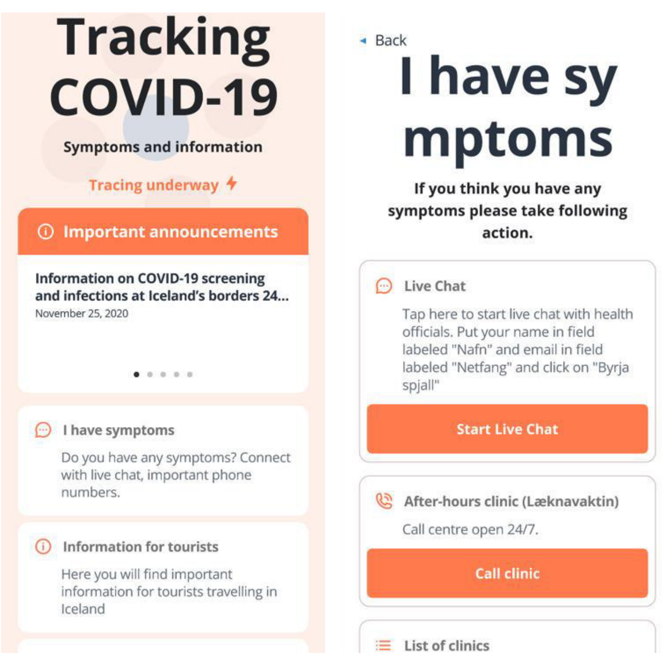

Fig. 3 Main page of Rakning C-19 (l); Options for help for users with symptoms (r)

displayed and there is the possibility to start a live chat with health officials if a user experiences any symptoms. This is shown in figure 3.

3) QR-Code-App

The country of New Zealand has developed an app, "NZ COVID Tracer", that performs contact tracing using QR-Codes. From the dashboard of the app it is possible to register where you are. There are two ways to do this. Either a QR-Code is scanned or a manual entry is created [20].

All stores as well as public transport like busses or cabs are obliged to put up official, government provided, "NZ COVID Tracer" QR-Code posters in highly visible places [21].

Users of the app are encouraged to scan the code before entering any such business or transportation. Whereas the manual entries should make it possible to record stays and meetings with people outside, such as on the playground, which is displayed in figure 4. Furthermore, it is possible to edit or delete old entries [20].

Another feature of the "NZ COVID Tracer" is the possibility to receive push notifications on your cell phone, if you have been suspected to be at the same place at the same time as a confirmed Covid-19 case. However, in New Zealand a Contact Tracer will always contact a suspected or confirmed Covid-19 case by phone. They conduct a personal interview. If persons are willing to share their digital diary with the ministry of health for further inspection they can do so after a process of verification of identity [20].

4) Additional features of tracing apps besides tracing

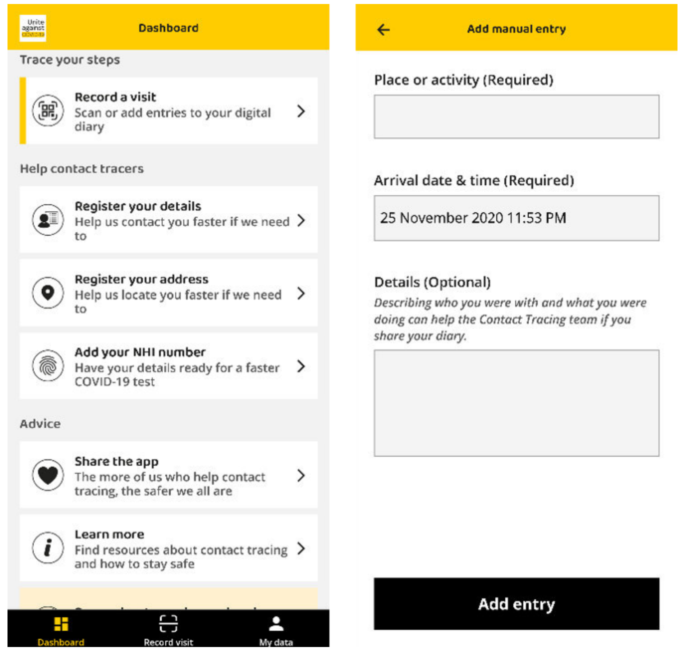

Fig. 4 Main page of NZ COIVD Tracer (l); Section for adding a manual diary entry (r)

Out of 27 EU countries, 19 countries published an app, all using Bluetooth technology. The aim is to enable cross-national contact tracing within the EU. To achieve this, the apps of the individual countries are to be linked with each other. 16 of the currently published apps are interoperable in theory. Already seven apps can communicate with each other.

In addition to pure contact tracing, many apps offer further functions. One quarter of the apps had the possibility to do a symptom check in the app or offered a link to a website, where such could be done. In most of the apps, either statistics about the infection in the respective country or general information about SARS-CoV-2 were displayed.

For the previously considered non-EU countries Iceland and New Zealand, additional functions could also be found in the app. It is possible to open a live chat with health experts in the Icelandic app "Rakning C-19". The New Zealand app "NZ COVID Tracer" on the other hand offers the possibility to store your own NHI number. This number is required in New Zealand when taking a Covid-19 test [20].

B. Privacy

In this chapter, the data protection concepts of the different Covid-19 contact tracing apps are presented. The focus is on which data is collected, how long it is stored, where it is stored, how authentication and verification take place and whether and how the collected data is pseudonymised. The table 1 below provides an overview.

1) What data is stored?

With the German contact tracing app, the following data is sent to the other smartphone and saved there. A random ID is sent, which changes regularly so that the smartphone cannot be identified via this ID. The Bluetooth protocol version, transmission power and reception strength, and the date, time and duration of the encounter are stored in the received phone [22].

The French app “TousAntiCovid” is another example of a Bluetooth based app. The app does not use the standards of Google and Apple, but the contact tracing algorithm was developed by the government. It also stores the meeting of two smartphones, with the proximity history of the two being stored. A cryptic ID is automatically created and sent to each other by the two smartphones [23]. The French app and the German app differ in their architecture. The creation and switching of the IDs work in another way. This is described in more detail in section 4.

In the Icelandic app “Rakning C-19”, an example of a GPS-based contact tracing app, the phone number is stored in a database and the smartphone stores the location data of the app users [24].

The New Zealand app “NZ COVID Tracer”, an example of a QR-Code based contact tracing app, stores data of people using the app and data of people providing QR-Codes for their location etc. They can enter their personal information such as first, last name and birthday, contact information like email and phone number, demographic information, the National Health Index (NHI), the locations visited with the date and time and Digital Diaries [25]. For those who request a QR-Code, their Global Location Number (GLN), first and last name, email address and whether they are valid or invalid will be stored [26]. The GLN clearly identifies locations and is a standard of the GS1 organisation [27].

2) Storage location

With the CWA and the “NZ COVID Tracer” app, the users' data is stored on the smartphone [22, 25]. With the French app, the random IDs are stored on the smartphone and a server [28]. In the Icelandic app, the location data is stored on the smartphone and the phone number is stored on a database [13].

3) Storage duration

For the German, Icelandic and French app, the data is stored for 14 days and after this time automatically deleted [22, 24, 28]. In New Zealand, the data of people who apply for QR-Codes and post them will be stored as long as the pandemic lasts and the data of people using the app will be deleted after 60 days [25, 26]. By deleting any of these apps, you can delete the IDs which are stored from this app on your device and the information you have entered.

4) Centralised and decentralized model

The CWA, the “Rakning C-19” and the “NZ COVID Tracer” app follow the principle of decentralised storage. An example of a centralised approach is the contact tracing app of France [23].

With the centralised model, the user must register with the app's central server. The server generates and sends an encrypted temporary ID to each device. This ID is exchanged between two people using the app when they meet. If a person tests positive, the server sends all stored IDs of people who have met to the server. The server decrypts all the IDs of the entire list and can thus decrypt and notify the contact persons of the infected person. In the decentralised model, the temporary anonymous ID is generated on the user's device and not on a server. If a person tests positive, they can voluntarily upload their random IDs to a server. Other users can download these IDs and the app compares the IDs from the infected list with the IDs you have had contact with [29]. The main difference between the decentralized model and the centralized model is that the matching of user ids in the decentralized model is not controlled by a server. Instead, the server merely transmits a list of positively tested ids, which are then compared on the respective smartphones.

5) Verification and authentication

To ensure that positive Covid-19 tests can be assigned to the right people and smartphones, the different apps use different authentication methods. With the CWA there are two variants of authentication. The first option is that the user receives a QR-Code from the test facility during test registration. The QR-Code contains a code that can be read by the smartphone with the camera and is encrypted by the app. The encrypted code is sent to the CWA server system. The server system sends the app a token, a digital access key, which is stored in the app. The token is linked to the hashed code on the server and the app deletes the code on the smartphone. To prevent a code from being assigned to several tokens, only one token is assigned to each hashed code. The test lab encrypts the token with the same mathematical procedure and stores the result with the encrypted token in the test result database. The app uses the token to regularly check the result list of the database. The token is assigned to the hashed code number and sent to the database. There the status of the test is queried and returned. With the token a unique assignment of the smartphone can be made. If the user is tested positive, this token is also used to trigger a warning. When the token is used, the app requests a TAN (transaction number), which is required to ensure that no false warnings are issued to users. The TAN confirms that a positive test result is available for the hashed code that matches the token of the smartphone. The second option would be via the phone if the test registration was not done via the app. The tested person is asked to call the app's hotline, where a hotline employee will ask questions to authenticate the person. The user receives a teleTAN, which was previously generated by the hotline employee in the server system. By entering this teleTAN in the app, it is transmitted to the server system for verification and provides the app with a token. The TAN is then requested with this token [22].

In France, when the test is carried out, contact details of the person and date of birth are stored. If a person has tested positive, they can register as positive in the app by sending a QR-Code or by manually entering a code. The date of birth must be entered for authentication [23].

With the Icelandic app, authentication is carried out by the National ID (NID). During the test you have to enter your phone number and the NID is determined. If you have tested positive, you will be asked to enter your NID when you receive a request to share your locations. The NID is compared with the NID stored in the request. If the entered NID and the NID from the request matches, you are verified [13]. For New Zealanders, the Covid-19 tester first checks whether the National Health Index (NHI) given is correct. The NHI is a unique identifier. The test person is asked for their name, date of birth and contact details by the test personnel and the NHI is checked against this information. If the person is confirmed positive, a contact tracker will contact the person. During the phone call, the contact tracker will ask the person about the places they have visited and the people they have seen. This can be done over the phone or by using the diaries of the app. You can send your entries via app. You will be asked to enter your personal details if you have not already

Italy and France, investigated the reasons why participants would install this Covid-19 app. A total of 5995 people was surveyed. At the time of the survey, there were no contact tracing apps on the market. For this reason, the functions and benefits of future apps were described in detail for the participants to get an idea of these apps. This description corresponded to the current CWA of Germany.

An important aspect is the perceived usefulness of users for contact tracing apps. According to the study [31, 32], the technology plays an important role especially for the protection of family and friends and is perceived as indirectly useful for reasons of social responsibility. However, the criticism remains that many respondents do not prioritise protecting their own health from Covid-19.

TABLE I

INFORMATION ABOUT CONTACT TRACING DATA IN DIFFERENT COUNTRIES

COUNTRY	DATA	STORAGE DURATION [DAYS]	MODEL	AUTHENTICATION	PSEUDONYMISATION
	• RANDOM IDs				
	• VISITED LOCATION • DIGITAL DIARY				
FRANCE	• CRYPTO-ID	14	CENTRAL	BIRTHDATE	RANDOM ID

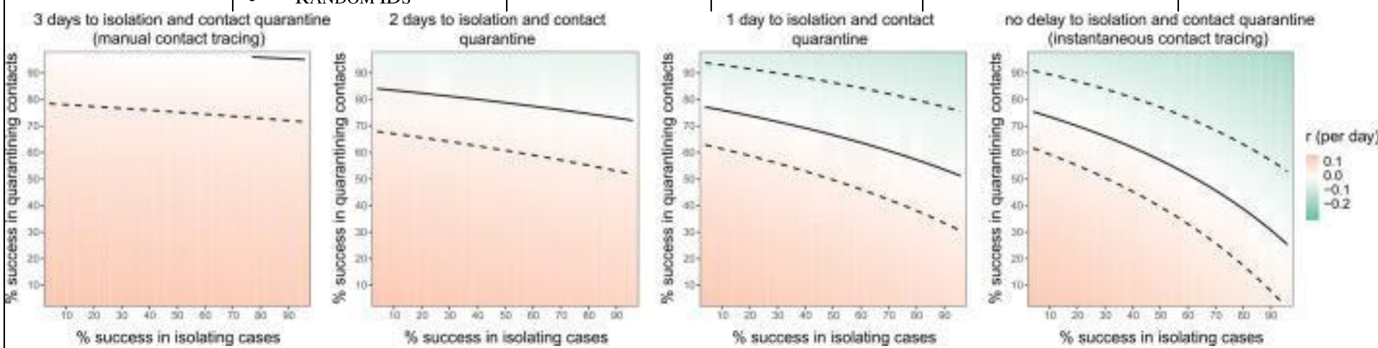

Fig. 5 Impact of the speed of isolation and contact quarantine [2]

done so. The contact tracker gives the positive person a verification code which enables the person to send their entries [20].

6) *Pseudonymisation and anonymization*

With the CWA and the “TousAntiCovid”, users are pseudonymised by constantly changing random IDs [22, 28]. It is also difficult to identify a person in the tests by encrypting the ID number. Data collected by the New Zealand app is encrypted in the database [30]. The communication between the app and the server in the app from Iceland is encrypted, also the location on your phone [13].

C. *Effectiveness and acceptance*

In addition to data protection, other central aspects such as the acceptance and effectiveness of Covid-19 apps play an important role.

Without a high level of public acceptance, the Covid-19 apps cannot fulfil their contact-tracking goal. The study [31], conducted in the United States, United Kingdom, Germany,

The survey shows that the respondents' acceptance of the app is very high. Many people care about protecting themselves as well as others and would be willing to install this app. For this reason, it is important not only to achieve a high level of acceptance, but also to achieve a high level of use of the app among the population. The effectiveness of a contact tracing app depends on the number of users. For contact tracing apps to be useful, more than 60 % of the country's population would need to have the app installed and activated, according to the simulation study by Ferretti et al [32, 33].

The study by [31] showed that a large part of the population would be willing to use the Covid-19 apps. The support is high in all countries, in all subgroups of the population. Approximately 75 % of respondents in all countries indicated that they would probably or definitely download the contact tracker app as part of the voluntary set up system. The reason most often cited against an installation is the concern that the government might use the app as a pretext for increased surveillance after the end of the epidemic [31, 34].

In contrast, according to a survey conducted by the opinion research institute “forsa” for the German Association of Towns and Municipalities, 73 % of users of the Covid-19 app in Germany would welcome a warning message that would also indicate the time and place of contact with an infected person. This could be achieved comparatively easily and in accordance with data protection regulations by means of an extension, with which the users of the app give their consent to the transmission of the time and place. In this way, the benefits of this digital tool would be significantly increased and the willingness to download and use the app would also increase. At the same time, it would make it easier for people to assess the potential risk of contact, such as whether it took place in the fresh air, whether a mask was worn and how long the contact lasted [35].

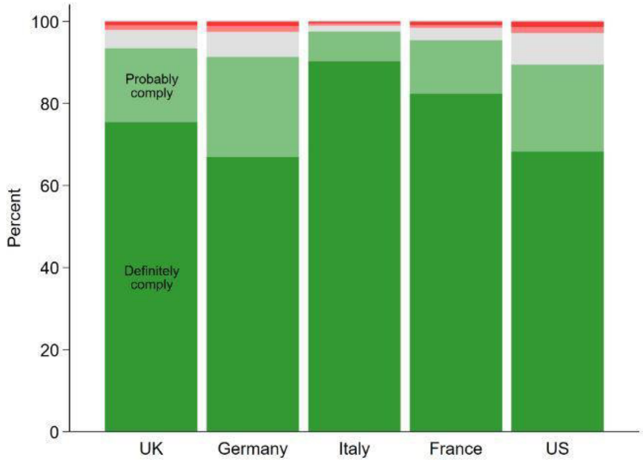

Fig. 6 Acceptance in case of self-isolation of 14 days [11]

In Germany, 21.4 million downloads were carried out at the time of the release. This corresponds to about 25.4 % of the population [4]. In Iceland and New Zealand, however, the app for contact tracing was already downloaded by 40 % of the population [9, 12]. Downloading the apps cannot be equated with using them, as the Bluetooth function can be switched off, for example. The usage figures could be significantly lower for this reason. According to the simulation by Ferretti et al., these coverages in the population is clearly too low for the apps to be effective. The low technical challenges can also not be due to the low user numbers of the apps, since they run on Android or IOS versions, which meet the needs of most users. The European apps that work with Bluetooth run on Android version 6.0 or higher, which 84.9 % of all Android users use [36].

Figure 5 shows the exponential growth rate of epidemic R as a function of the success rate of immediate isolation of symptomatic cases and the success rate of immediate contact tracing. The reproduction factor (R) describes how many people an infected person infects on average [37]. The different panels show the variation in the delay associated with the intervention, from symptom onset to isolation of cases and quarantine of contacts. Not only at low coverage, but also at a coverage of more than 50 %, the absence of risk contacts does not at all mean the all-clear for an app user, as at low coverage almost all risk contacts with infected persons are not detected. Even with a coverage of 60 % for infected persons, about 60 % of their contacts still have to be traced so that the reproduction factor would fall below 1, shown in figure 5 [33]. So, this means that after a lockdown, about 60 % of the population would need to install the app and use it consistently to reduce the spread of the virus while minimising the number of people quarantined. Lower app usage rates would lead to a renewed increase in infection numbers and corresponding countermeasures. As this is a simulation study, growth rates may vary widely across the globe. In addition, the infectivity of asymptomatic, infected individuals and that of pre-symptomatic transmission is not sufficiently known, which means that these results could be different depending on the situation or region.

Based on our research, no current studies or papers could be found that analyze the reasons for the low acceptance of the Covid-19 apps.

It could be shown that a warning app is almost ineffective if it is actively used by only a very small part of the population. As a result, contacts with freshly infected but already contagious people can be undetected and infection chains cannot be interrupted early on.

Another important point is the effectiveness of Covid-19 apps. Of course, acceptance plays an important role for effectiveness. However, there are other factors which limit the effectiveness. There is the problem that in Germany, for example, the risk group of over 70-year-olds is estimated to be four million non-users of a smartphone [33].

In addition, the Covid-19 apps are very much dependent on the speed of the test procedures. With a rapid testing procedure, even late-diagnosed cases could be traced to identify recently infected people before they develop symptoms and go on to infect people.

Most apps, such as those in Germany or New Zealand, rely on community-based testing. Since it is not possible to track individuals, self-isolation plays an important role in the effectiveness of an app. People at high risk should go into self-isolation if the Covid-19 warning app indicates this. Respondents were also asked by Altmann et al. how likely they were to comply with the request for self-isolation for 14 days if they were in close contact with a person classified as infected [31, 38].

As shown in the figure 6, the majority of respondents in all countries indicated that they would comply with the request for self-isolation. Support is highest in Italy, where 89 % of the respondents are to comply [31, 38].

It is difficult to make a precise statement about effectiveness and efficiency. Simulations and studies have shown that if a cell phone for contact tracing was immediately notified, it could be sufficient to stop the epidemic if a sufficiently high proportion of the population used it. This rapid method of contact tracing can ensure that contact persons are isolated more quickly, thereby reducing the number of infected persons. This approach, using a cell phone application that implements immediate contact tracing, could reduce transmission to an $R < 1$ level and achieve sustained suppression of the epidemic, stopping the further spread of the virus.

IV. Discussion

Different contact tracing apps were considered. These are used to interrupt and trace chains of infection. There are three different basic technologies that are used for this purpose. In some countries mixed forms of these technologies are used.

Most of the apps used are based on Bluetooth and use the standard developed by Google and Apple. With the Bluetooth technology it is possible to measure the exact distance of two smartphones. The alternatives based on QR-Codes or GPS data. With these, no precise measurement of the distance between devices is possible. On request at the Icelandic Ministry of Health, it emerged that Iceland was planning a new app that would also use Bluetooth technology. New Zealand also intends to add this technology to its existing app.

When developing the apps, many countries paid attention to strict data protection concepts. Most apps collect as little personal data as possible. The New Zealand app requires users to provide their contact details so that they can be contacted in case of potential risks. In the German app, however, only random IDs are exchanged so that no one can be traced back to individuals. The contact tracing of South Korea represents a major invasion of privacy. There, the state monitors citizens via an app, as well as through other measures such as public cameras or tracing of bank transactions.

The effectiveness of Covid-19 tracing apps depends on several factors. It is of great importance that the majority of the population uses the tracing app. Without a high participation of the population, it is not possible to trace enough contacts to break the chain of infection. For the app to be downloaded as often as possible, a high level of acceptance among the population is required. To achieve this acceptance, data protection is an important factor. It is important for the user to provide as little data as possible and to manage it securely. For contact tracing, looser data protection concepts would be more helpful, since in Germany, for example, only half of the potentially divisible test results are shared. If the test results were automatically shared, more potentially infected contacts could be informed. However, this would be a breach of privacy. A balance must always be found between acceptance and data protection.

One country where the balance has been disregarded is South Korea. The paper [39] describes South Korea's approach to contact tracing. While most contact tracing strategies in most countries use smartphones or contact lists, South Korea relies entirely on technology. There are seven different ways of identifying a person's contacts and tracing their movements. The smartphones are used to track the location. With the help of the immigration office, immigration protocols are viewed. The South Korean police can track people on the street with many digital cameras that have face recognition. Payments and locations are tracked through credit, debit and prepaid card payments. The purchase of bus tickets can also be tracked through the bank or public transport companies. Government agencies are able to request personal information and prescriptions and medical records can be tracked through insurance companies and hospitals. Through these various sources of information, South Korea can trace the chain of infection. Through these measures, South Korea was able to contain the spread of the virus.

Another aspect that influences effectiveness is the speed of the test results transmitted. The longer the transmission of test results takes, the later the contact persons of an infected person are informed about the contact. As a result, they later become self-isolated and potentially infect other people. This makes it more difficult to break the chain of infection.

Many elderly people, who often belong to the risk group, do not own a smartphone. However, it would be of great importance for these people in particular to be informed if contact had been made with potentially or confirmed infected persons. At the moment there are hardly any alternatives besides apps. Thus, people without smartphones or very old smartphones are denied the opportunity to participate in contact tracing. To counteract this, a "Corona Warning Band" is currently being developed in Germany. It is a wrist band and should be able to record encounters with users of the German CWA and other Bluetooth bands.

Another possibility already offered in New Zealand is an analogue contact diary. Although this data cannot be transmitted digitally, a structured recording of contacts can help to ensure that no meetings are forgotten when the health authorities ask for them. What must be kept in mind, however, is that in an analogue book only the names of acquaintances can be recorded. Encounters with strangers, on the other hand, cannot be recorded meaningfully.

Since apps alone are not a panacea, alternatives to apps should continue to be developed so that nobody is excluded from contact tracing. However, it would be best if these alternatives could also communicate with existing apps. This could further increase the effectiveness of contact tracing.

In addition, further studies need to be conducted regarding acceptance and effectiveness. It needs to be investigated why the acceptance was very high at the beginning of the pandemic but very low when the apps were introduced. Furthermore, it needs to be shown how many people need to use the app in order to be useful, as only simulation studies are available in this regard so far.

V. Conclusion

Many countries have developed contact tracing apps in the fight against Covid-19. The Bluetooth technology has been established for these apps. There are other options that have implemented contact tracing using QR-Codes and GPS. Some of these apps are considering switching to Bluetooth or adding this component. With this technology the exact distance between two smartphones can be calculated. The distance has an influence on the epidemiological risk of transmission and is therefore an important indicator for contact tracing.

Data protection is a high priority for most apps. They try to collect as little personal data as possible from the user. Despite these measures the acceptance of the apps in the population is low.

No statement can be made about the effectiveness of the apps at this time. There are only simulation studies regarding the effectiveness.

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Detection Accuracy of Different Deep Learning Algorithms for Covid-19 on chest X-Ray and CT: A systematic review and meta-analysis

D. Bessaheken, H. Mobinzada, S. Zhao

Abstract—

Objective: The purpose of this study is to conduct a systematic literature review with a meta-analysis to determine the detection accuracy of different Deep Learning algorithms for COVID-19 on X-ray (CXR) and CT scans**.**

Methods: Searches were conducted in the online article databases PubMed, Springer, Science Direct and medRxiv/bioRxiv, and MDPI according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines to identify all potentially relevant studies published. Studies reporting data on True positive (TP), true negative (TN), false positive (FP), false negative (FN) as well on sensitivity, specificity, accuracy and F1-scores of Deep Learning algorithms for COVID-19 were included. Paired forest plots were employed to analyze the sensitivity and specificity of the algorithms on both CXR and CT datasets; boxplots for comparing the accuracy and F1-Scores of the algorithms between these two imaging modalities. Summary receiver operating characteristic (SROC) plots were applied to assess the overall performance based on the AUC (area under the curve) of the algorithms on both CXR and CT datasets and the frequency of use of each algorithm are presented in bar graphs.

Results: From an initial set of 596 articles, a total of 44 articles were finally selected through an extensive inclusion-exclusion process and conducted for a systematic review and meta-analysis. 30 and 27 algorithms for Deep Learning applied respectively on Chest CT and CXR datasets were identified.
The meta-analysis showed that, almost all algorithms achieved an excellent performance for the detection of the COVID-19. However, it could be noticed based on the analysis of the F1-Score that, deep learning algorithms applied on chest CT datasets have a better performance that those applied on CXR. Based on CT datasets the area under the curve from the SROC for the ResNet-50, COVIDNet-CT and ResNet-18 methods was over 95% and for VGG-16 over 90%. GoogleNet, AlexNet and ResNet-18 achieved on CXR datasets an AUC over 95% from the SROC. These algorithms stand out slightly from the others and are therefore excellent classifiers for the detection of the COVID-19.

***Index Terms*— Covid-19-Deep Learning; algorithms; Chest CT; Chest X-ray; Accuracy**

I. INTRODUCTION

Coronavirus disease or COVID-19 is an infectious disease which came to light on December 31, 2019 when China notified to World Health Organization (WHO) of a pneumonia like infection due to unidentified cause observed among people in Wuhan city of Hubei province in China [45].

The virus outbreak has spread rapidly, considerably affecting all continents with more than 79 million people infected and over 1.7 million deaths [46].

The virus spreads through saliva droplets or secretions of swab from the nose. A COVID-19 infected person may experience tiredness, dry cough, muscle pain, loss of taste or smell, headache, fever, sore throat chest discomfort and difficulty in breathing [47].

However, older people and those with underlying health conditions such as diabetes, cardiovascular disease, chronic respiratory disease and cancer are at greater risk of serious illness.

Due to an unknown cause of pneumonia-like infection and its ability to generate new strain by mutation, it is almost impossible to provide a cure for COVID-19 patients in the form of vaccine or medication. Hence, according to the WHO, more tests are required, and social distancing has begun in practice among people living in high-alert geographical areas in different countries affected by the corona pandemic. In the affected countries, reverse transcription polymerase chain reaction (RT-PCR) serves as the gold standard diagnostic method for identifying the coronavirus infection. The test is designed to detect the viral RNA in respiratory specimens such as nasopharyngeal swabs or bronchial aspirates However, RT-PCR testing tends to be deficient in many areas. The test also suffers from inadequate sensitivity, as shown by the 71% of cases reported in Fang et al. [48]. This is due to many factors, such as sample preparation and quality control [49]. In addition, the test takes 4 to 6 hours or even a whole day to deliver the results. Since the test takes more time to generate the result than the time it takes for the coronavirus to spread among people, it can sometimes lead to false negative results if the amount of the virus genome is insufficient or if the correct time window for virus replication is not observed [50]. In order to test the COVID-19 infection more quickly and efficiently, CXR and / or CT images of COVID-19 suspects could therefore be an answer.

Easily accessible and traditional imaging equipment, such as CXR and thoracic CT, provide in clinical practice tremendous support to clinicians, radiologists and medics in healthcare and in medical imaging. These both technologies have been used in medical diagnosis for several decades since they were introduced. In many severely affected regions, it is difficult to supply a sufficient number of RT-PCR test kits to test for COVID-19 infection among thousands of suspected corona patients [54]. Therefore, to address this issue, the detection of the COVID-19 infection can be performed using CXR and CT scan images of corona suspects suffering from COVID-19 symptoms.

Much research came up with a solution by developing Deep learning-based systems [56] for automatic detection of the COVID-19 infection from Chest CT and CXR scans.

The main purpose of using deep learning models is to attain higher accuracy of classification with CXR and CT scan images by distinguishing the COVID-19 cases from non-COVID-19 and/or other pulmonary infections cases. It is known that training a deep model requires a large number of sample images from both COVID-19 and non-COVID-19 patients in order to make the model's learning about the patterns more effective.

As the literature on COVID-19 grows exponentially, it is increasingly difficult for physicians to keep abreast of scientific advances. We therefore systematically reviewed the existing literature on various Deep Learning Algorithms for detecting COVID-19 on CXR and CT scans. Our meta-analysis aims to compare the detection accuracy of different Deep Learning algorithms for COVID-19 from these both imaging modalities.

II. Material And Methods

In this study, a systematic literature review was conducted to achieve the research goal. This was conducted according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework.

A. Search strategy

For the selection of primary articles, the major electronic databases PubMed, Springer, ScienceDirect, medRxiv/bioRxiv and MDPI were searched for related articles. The search syntax contained the following search terms: "COVID-19", "Machine learning", "Deep Learning", "Diagnosis", "Detection", "Chest X-Ray", "Chest CT" combined with the boolean operators "AND" and "OR". The following search query syntax was used for the literature search: (((covid-19) AND (machine learning OR Deep learning)) AND (Diagnosis OR detection)) AND (Chest X-Ray OR chest CT).

B. Eligibility criteria

This research focused on peer-reviewed publications, as well as preprints in which Deep Learning techniques were applied to diagnose or detect COVID-19 on CXR or CT datasets.

The software program "Zotero" was used to manage all these publications, their references and the removal of duplicates.

Articles were included in this systematic review if they met all the following eligibility criteria:

- Original research papers;
- Aimed at diagnosis of COVID-19;
- Evaluation of any Deep Learning method;
- Using CXR or CT datasets for screening of COVID-19
- Reporting data on the accuracy of the algorithms (e.g., sensitivity, specificity, accuracy, AUC or F1) or reporting data on true positives (TP), false positives (FP), false negatives (FN), and true negatives (TN) rates
- Written in English

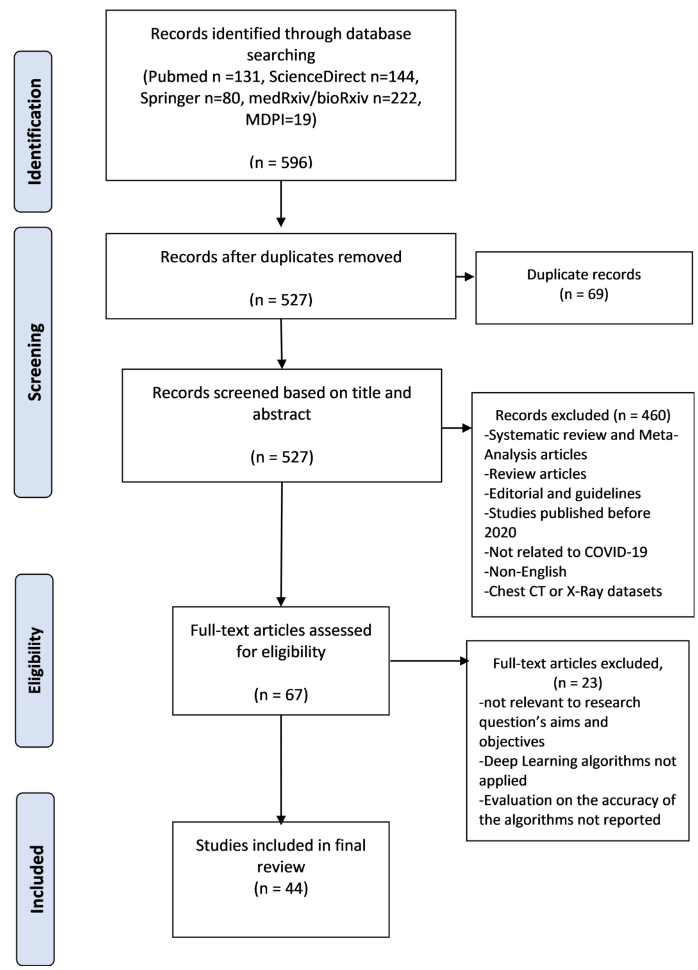

Figure 1: *PRISMA flow diagram showing the research process of the systematic review.*

The exclusion criteria were the following:

- Studies published before 2020
- Duplicates studies
- No full text available

C. Data extraction

We first examined the included studies according to the datasets to separate them into CT and CXR. The following data were extracted: general study details (authors, published date, and sample size), deep learning methods and diagnostic test results (true positive, true negative, false positive, false negative, accuracy, sensitivity, specificity and F1-Scores). The number of different classes (classification of COVID-19 from non-COVID-19 or/and from other – viral/bacterial – pneumonia) has been extracted as well.

D. Statistical analyses

In the meta-analysis numerical values for sensitivity and specificity were obtained with a 95% confidence interval based on the TP, TN, FP, FN of the included studies and presented in

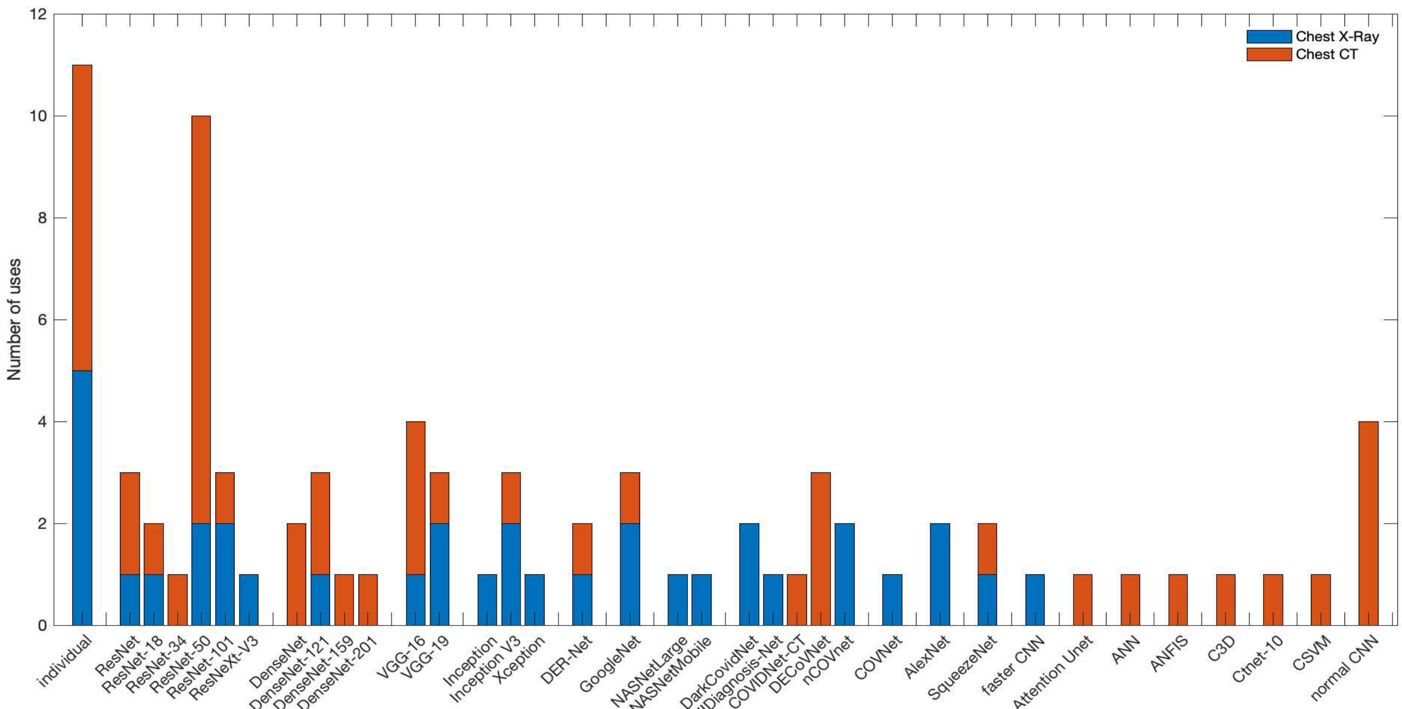

Figure 2*: Frequency of use of different deep learning methods based on CXR and CT in studies. The x-axis is algorithm, and the y-axis is the number of studies, which used the correspond algorithm.*

forest plots. The sensitivity refers to the ability of the test to correctly identify those patients with the disease. It is calculated with TP/(TP+FN). The specificity represents the ability of the test to correctly detect those patients without the infection. It is calculated as TN/(TN+FP). The closer the values are to the value 1 the better are the results of the algorithms.

The recommended method to calculate the confidence interval was introduced by R. G. Newcombe and D. G. Altman [53]. If r is the observed number of subjects with some feature in a sample of size n then the estimated proportion who have the feature is p = r / n. To get the 100(1 - a) % confidence interval, the first step is to calculate the 3 quantities

$$A = 2r + z^2;\ \ B = z\sqrt{z^2 + 4rq};\ \ and\ C = 2(n + z^2)$$

where z is the 100(1 - a/2) percentile from the standard Normal distribution. Then the confidence interval for the population proportion is given by

$$\frac{A - B}{C} \quad to \quad \frac{A + B}{C}$$

The Confidence interval using this method can be symmetrical or asymmetrical to p.

The summary receiver operating characteristic (SROC) curves for both CT and CXR datasets were then applied to assess the overall performance of each algorithm from multiple study results by the area under the curve (AUC). The shape of the SROC curves and the area under the curve (AUC) help us estimate the discriminative power of a test. The closer the curve follows the upper left-hand corner and the larger the area under the curve, the better the test is at discriminating between those with and without the disease.

The criteria for AUC classification are 0.90-1 (excellence), 0.80-0.90 (good), 0.70-0.80 (fair), 0.60-0.70 (poor) and 0.50-0.60 (failure) [51].

Because of the “accuracy paradox” of some models, F1-score was used as well as a performance metric to compare the detection performance of the algorithms between the 2 imaging modalities (chest CT and CXR). To this end boxplots were used. The accuracy metric alone is typically not enough information for evaluating the robustness of a model since it can be misleading due to the “Accuracy paradox” [52]. Indeed, a model can predict the value of the majority class for all

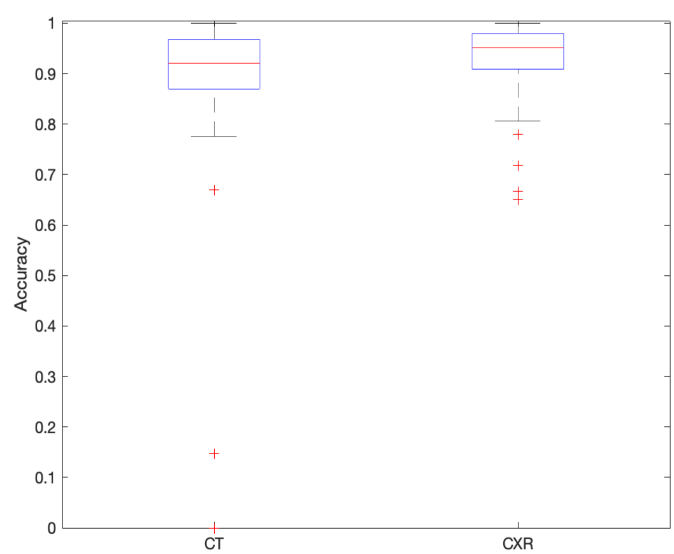

Figure 3*: The Accuracy score of different algorithms based on CT and CXR*

Red line (50% of the data), red plus (outlier), lower boxline (25% of the data), upper boxline (75% of the data), upper antenna (maximum), lower antenna (minimum except outlier), Interquartile range (IQR): 1,5.

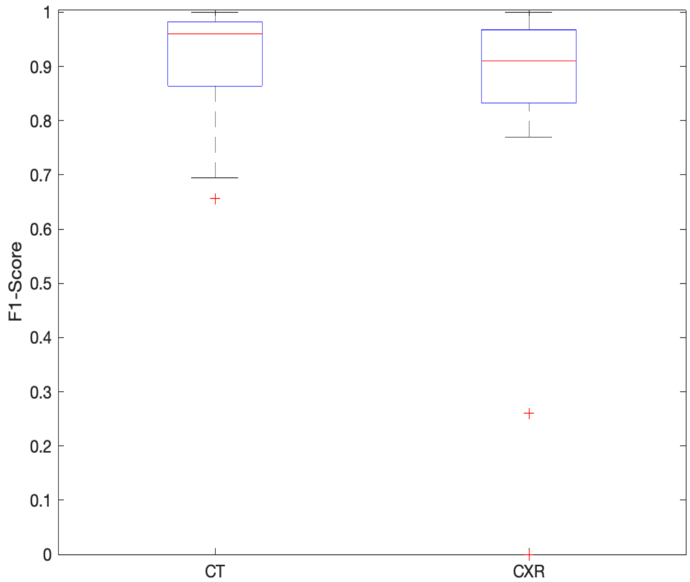

Figure 4: *The F1 score of different algorithms based on CT and CXR Convention is described (Figure 3)*

predictions and achieve a high classification accuracy although this model is not the best and not useful in the problem domain. This situation happens when data are imbalanced (where most of the instances belong to one of the classes).

Data were processed using Review Manager 5.3 (RevMan 5.3) and Matlab R2020b.

III. RESULTS

A. Search results

Succeeding the systematic search process, 596 publications were retrieved. Of these, 69 duplicate publications were removed, leaving 527 potentially relevant articles for title and abstract screening. After the screening, an additional 460 publications have been removed and 67 publications were retained for a full-text evaluation. These were assessed for eligibility, resulting in 44 total publications fulfilling inclusion criteria and included in the quantitative analyses (meta-analysis). This systematic search process is illustrated in the PRISMA flow diagram (**Figure 1**).

Based on the results of the systematic review, a total of 44 studies were analyzed by meta-analysis. Data on chest CT were reported from 26 articles [1-18,20-27], 17 studies [28-44] retrieved data on CXR and 1 paper in common [19] provided data both on chest CT and X-ray scans.

The extracted data (mentioned in section **II-C)** from the included studies on both datasets are presented in **Table 1** (CT-dataset) and **Table 2** (CXR dataset).

The data size represents the number of chest CT/X-ray samples used to perform the detection of the COVID-19 infection. Classes represent the classification of data into COVID-19 or non-COVID-19 (2 classes); COVID-19, non-COVID-19 or other pneumonia (3 classes) and into COVID-19, non-COVID-19, bacterial pneumonia or viral pneumonia (4 classes). Some preprints have been included as well in this review, since they met the selection criteria [1] [3], [7] [9] [11] [19] [23] [27] [34] [40].

B. Analysis of the frequency of use of different deep learning methods

A stacked bar diagram was created to depict the frequency of use of the algorithms reported in the included 44 articles. 27 (incl. 5 different individual deep networks) and 30 (incl. 6 different individual deep networks) Deep Learning algorithms respectively applied on CXR and CT datasets were identified (**Figure 2**).

For the studies applied on CXR dataset, the most used are the ResNet algorithms (7 studies) with different number of layers followed by the Inception (4 studies) algorithms. ResNet algorithms are easier to optimize and can gain accuracy from considerable depth. It was developed to address the vanishing-gradients problem. Comparing to other algorithms, they are easier to train in a deeper depth [58]. It could also be noticed that many individual deep networks with their own architectures have been applied. In addition, algorithms specific to COVID-19 (DarkCovidNet and COVIDiagnosis-Net, NCOVnet) disease were used just as often (5 studies).

The ResNet neural network algorithms stands out as well for the studies applied on chest CT data. Especially ResNet-50 has been used in 8 papers. DenseNet is another common neural network based on CT (6 studies). It alleviates the vanishing-gradient problem, strengthen feature propagation, encourage feature reuse, and substantially reduce the number of parameters [59].

Furthermore, there is the VGG network, which is used 4 times in the studies and normal CNN applied in 4 papers. Similar to the studies applied on CXR data, many individual deep networks were applied as well. DECoVNet and COVIDNet-CT are algorithms in the reported studies which were specifically implemented for COVID-19 and applied on chest CT data. They are used respectively in 4 and 1 studies.

C. Quality of classification results

1- Comparison of the detection accuracy of the algorithms between CXR and Chest CT Using the accuracy and F1-Score metrics

Using data from the analyzed original articles, the distribution of the accuracy score of CXR and CT-based algorithms was compared using a boxplot presented in **Figure 3**. 54 and 45 values of the algorithms' accuracy based respectively on chest CT and CXR datasets taken from 22 and 18 studies were identified. In addition, the distribution of algorithms based on the F1 score, which is presented in **Figure 4**. For this purpose, 43 F1-score values of algorithms based on CT from 16 studies were compared with 23 F1-scores of algorithms based on X-Ray taken from 11 studies.

The boxplot presenting the accuracy score shows that, the median of the algorithms trained on chest CT dataset (0.93) is lower than of the algorithms applied on CXR (0.95). However, in the box plot reporting the F1-score, the median of the models using chest CT dataset (0.97), was found higher than the median of algorithms applying CXR (0.92).

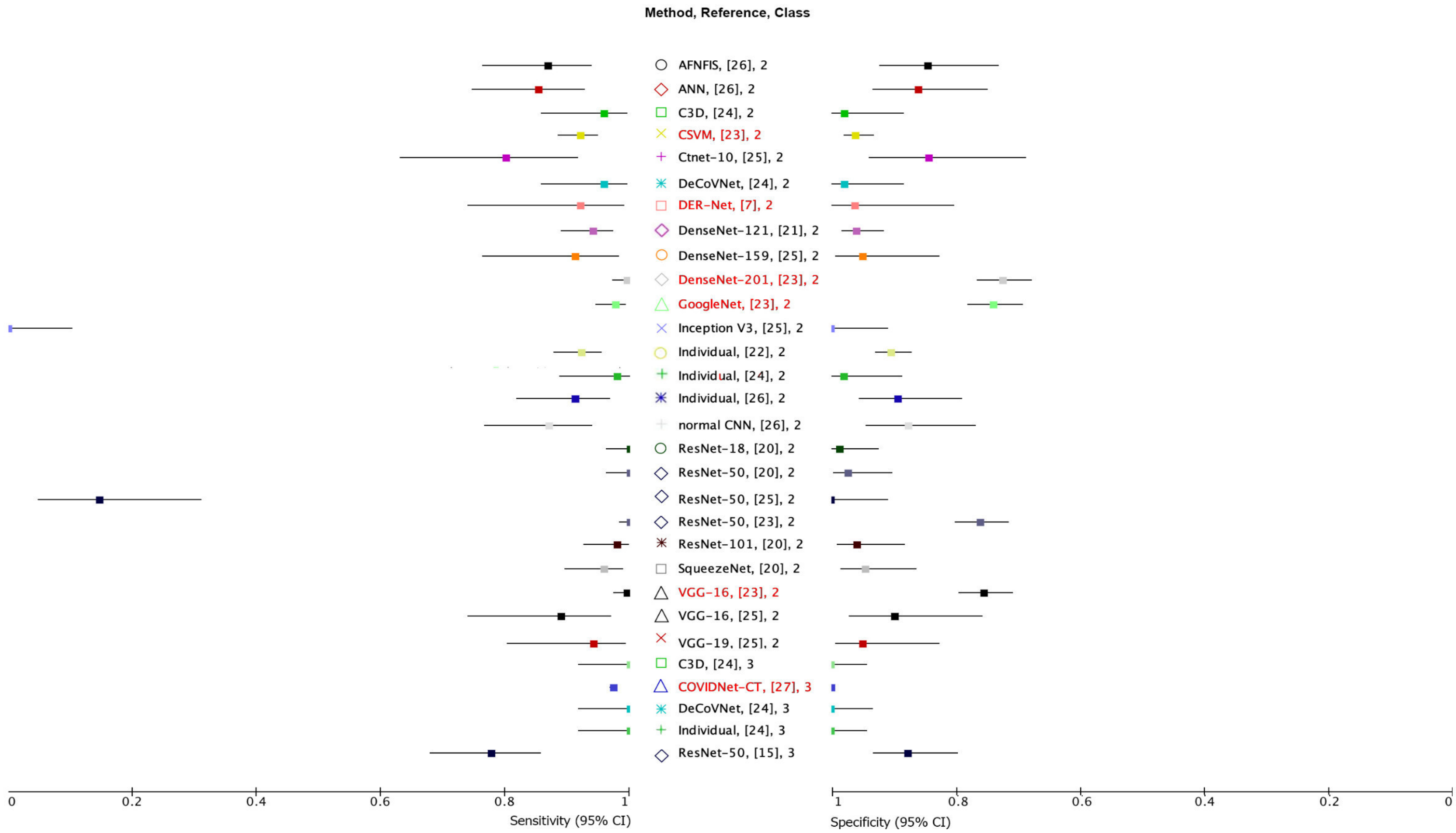

Figure 5*: Forest Plot COVID-19 detection using algorithms based on chest CT images. Algorithms are sorted by class and name. Red marked algorithms are preprints.*

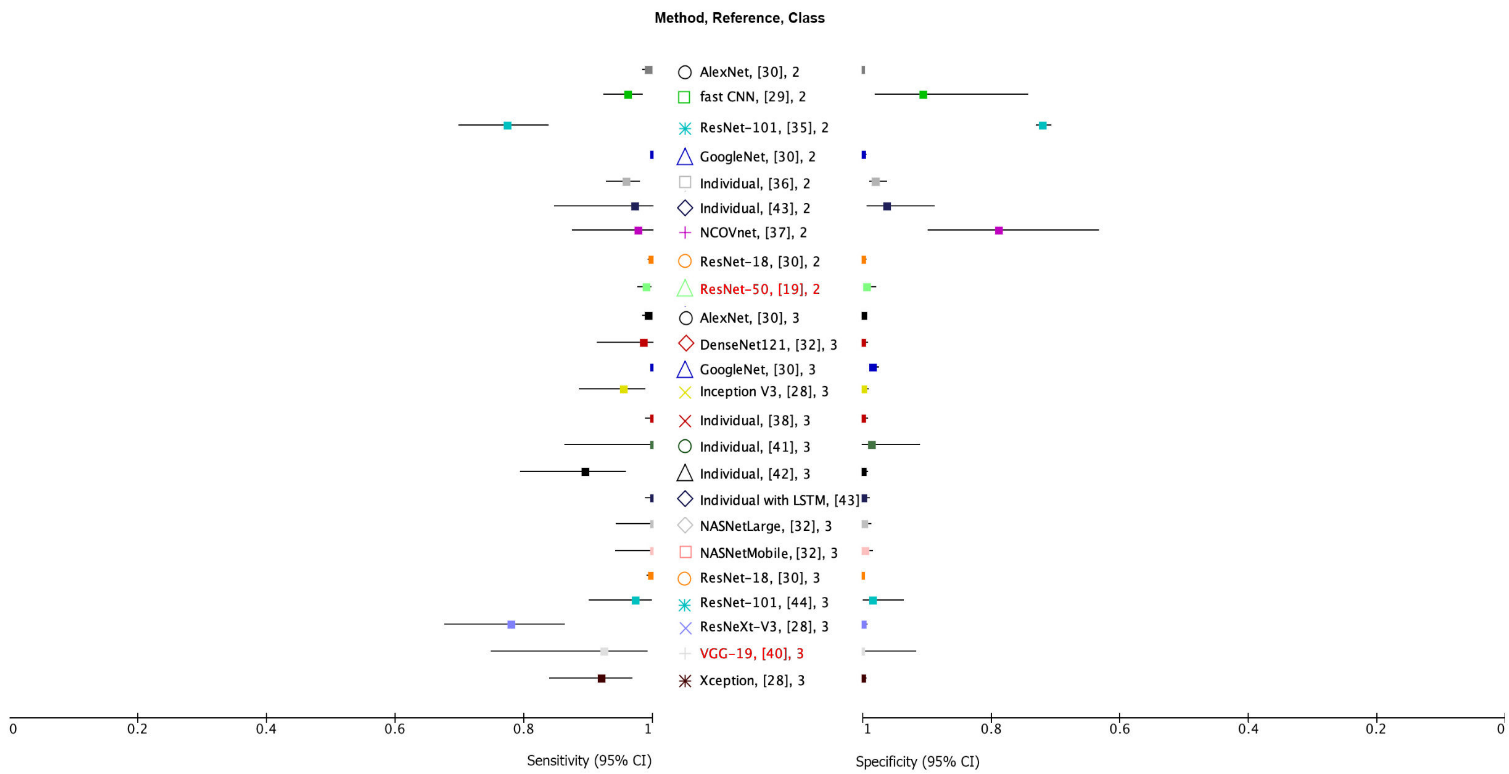

Figure 6*: Forest Plot COVID-19 detection using algorithms based on Chest X-Ray images. Sorting equals (Figure 5)*

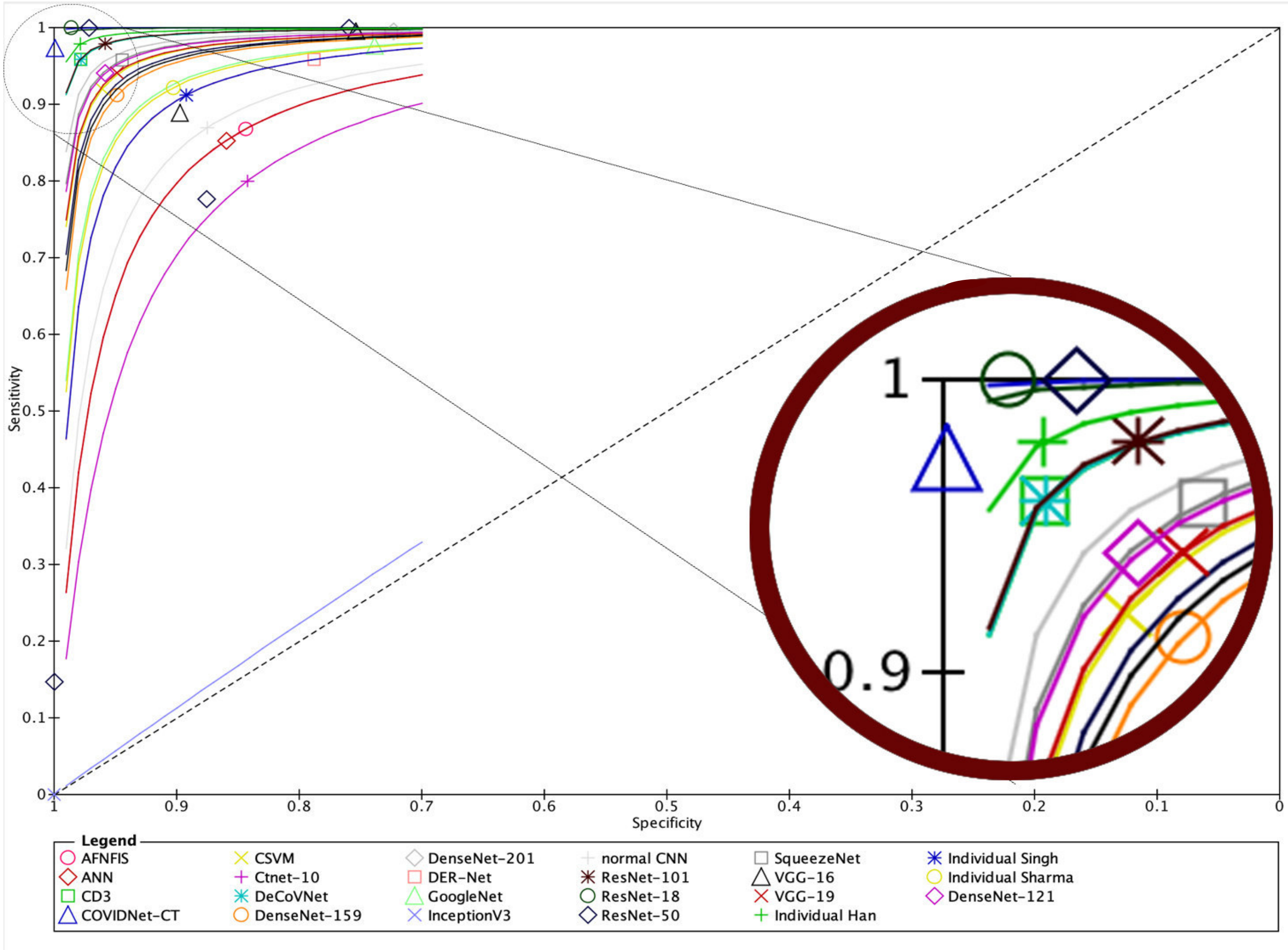

Figure 7: *SROC plot COVID-19 detection using algorithms based on chest CT images.*
The symbol and color of each algorithm correspond to those used in the forest plot (Figure 5) for the same algorithm.

After an overall evaluation of the performance of CXR compared to CT for the detection of COVID-19, it is more interesting to analyze the performance of each algorithm in detail using metrics such as sensitivity, specificity and then the AUC from the SROC.

2- Evaluation of the sensitivity and specificity of algorithms

a. Evaluation based on the chest CT dataset

Since some studies did not specify the values of sensitivity, specificity and their corresponding confidence interval (CI), only the one reporting the values of TP, FP, FN, TN were included in the forest plot in **Figure 5**, as the CI can easily be calculated from these values. It shows 10 different studies [7,15,20-27] with a total of 26 methods illustrated in a forest plot.

The sensitivity values of these algorithms were between 0 and 1, while the specificity values were between 0.72 to 1.

b. Evaluation based on the CXR dataset

In **Figure 6** only studies reporting the values of TP, FP, FN, TN were included in the forest plot as the CI of the sensitivity and specificity can easily be calculated from these values. Thereby, 14 different studies [19,28-30,32,35-38,40-44] reporting these data were included with a total of 24 methods illustrated.

The lowest sensitivity value is 0.77 and the highest is 1. For the specificity value, the range is smaller, here the lowest is 0.72 and the highest equals 1.

3- Evaluation of the overall performance of the algorithms using AUC from the SROC

SROC (Summary Receiver Operating Characteristic) plots were based on the results of the corresponding forest plots.

a. Evaluation based on CT dataset

The SROC curve of algorithms used in studies based on chest CT images is illustrated in **Figure 7.** Two of the 4 studies with an Area Under Curve (AUC) > 95% which described the COVID-19 classification using ResNet-50 algorithm were classified into excellent category, 1 of 4 studies was classified into good category, while the other 1 study was classified into poor category. One of 2 studies with AUC > 90% using VGG-16 algorithm was classified into excellent category, while the other 1 was classified into good category. The study with AUC < 60% applying the InceptionV3 algorithm was classified into failure category. The 2 studies training respectively the COVIDNet-CT and ResNet-18 algorithms with AUC > 95% were classified into excellent category. The Ctnet-10 algorithm applied in 1 Study shows an AUC between 80% and 90% and therefore was classified into good category. The other

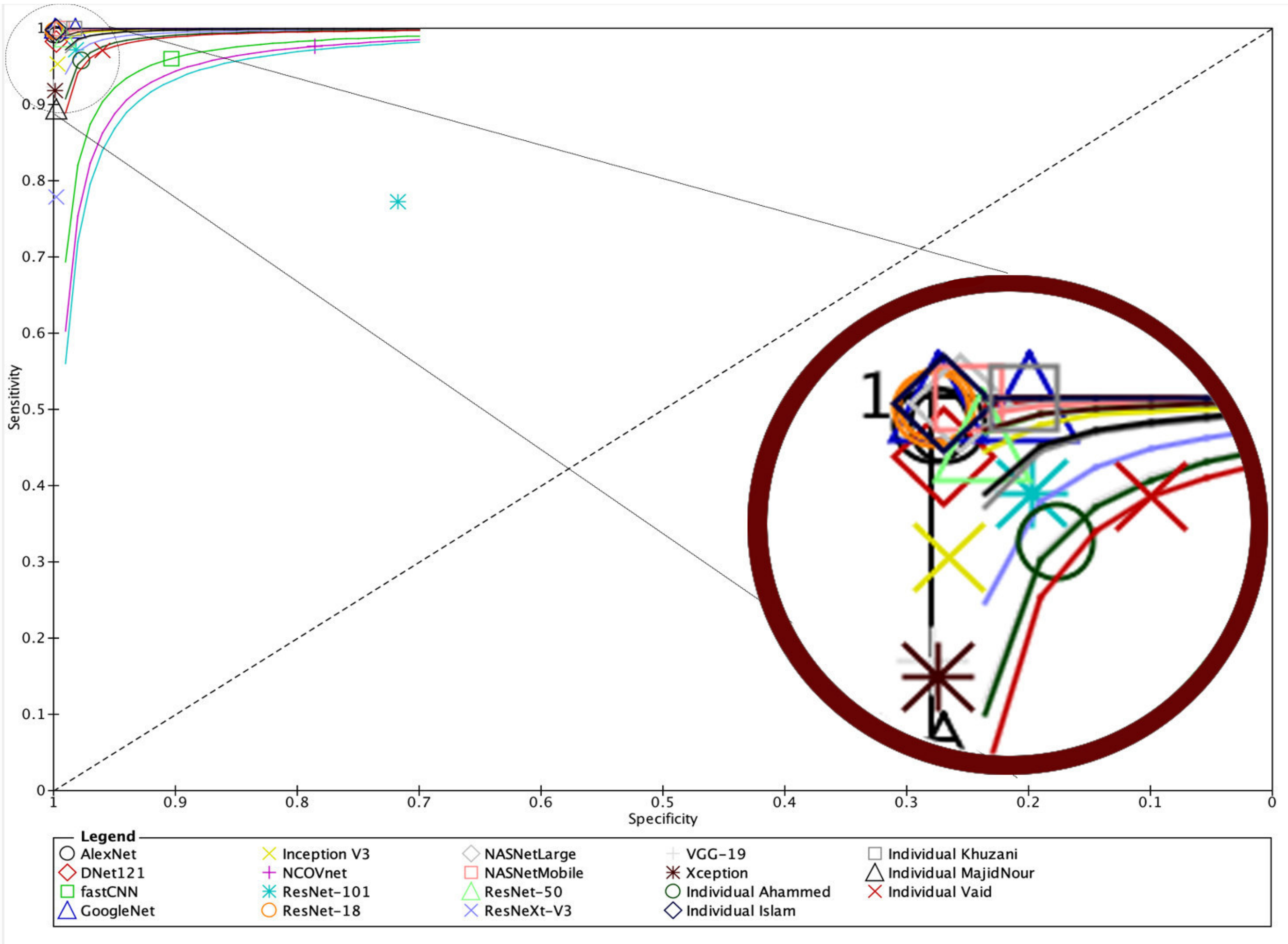

Figure 8: *SROC plot COVID-19 detection using algorithms based on Chest X-Ray images.*
The symbol and color of each algorithm correspond to those used in the forest plot (Figure 6) for the same algorithm.

algorithms showed an AUC > 90% and were thereby classified into excellent category but used respectively only in 1 study.

b. Evaluation based on the CXR dataset

The SROC curve of algorithms used in studies based on CXR images is illustrated in **Figure 8**. One of 2 studies with an AUC > 95% which describes COVID-19 classification using ResNet-101 algorithm was classified into excellent category, while the other 1 was classified into fair category. GoogleNet, AlexNet and ResNet-18, each applied respectively on 2 studies presented an AUC over 95%. All the other algorithms showed an AUC > 90% and were classified into excellent category. These algorithms were used in only 1 article each.

IV. Discussion

Since RT-PCR tests present some limitations (risk of false negative, possible shortages of test kits) [55], easily accessible and faster methods such as CXR and chest CT are used to detect evidence of COVID-19 infection [57]. Currently, the detection of COVID-19 using these imaging modalities necessitate highly experienced physicians since there is overlapping with several other lung abnormalities. Therefore, manual detection of COVID-19 can delay the diagnosis and initial treatment process. To address this issue, deep learning-based systems [56] have been established to detect automatically the COVID-19 infection from Chest CT and CXR scans and to reach higher accuracy of classification by distinguishing the COVID-19 cases from non-COVID-19 and/or other pulmonary infection cases.

To the best of our knowledge, this is the first systematic review and meta-analysis to collate the available evidence on the accuracy parameters of different deep learning methods for the detection of the COVID-19 infection on CXR and chest CT. 44 papers reporting a considerable amount of Deep Learning algorithms were included. 27 (incl. 5 different individual deep networks) and 30 (incl. 6 distinct individual deep networks) algorithms were identified, respectively applied on CXR and CT datasets. Values of sensitivity, specificity, accuracy and F1-Scores were used to evaluate the diagnostic accuracy of the identified deep learning methods. For this purpose, a meta-analysis was conducted including a variety of graphical representations, each elucidating a different aspect of the diagnostic performance.

To analyze the overall performance of each algorithm, the results from the forest plots were represented in the SROC charts. Almost all the studies showed excellent classification performance on datasets and it was not an evidence to determine the best classifier on detecting the COVID-19 infection on chest

CT and CXR. However, based on CT datasets, the ResNet-50 method stood out with 2 studies from 4 studies achieving an estimating AUC from the SROC over 95%. COVIDNet-CT and ResNet-18 trained in 1 study each, achieved approximatively the same AUC percentage. VGG -16 used in 1 paper achieved an AUC from the SROC over 90% as well. GoogleNet, AlexNet and ResNet-18, each applied respectively on 2 studies, sticked out on CXR datasets reaching AUC results over 90% for the SROC plot. It is remarkable that the networks mentioned above are all variants of the CNN architecture. In general, algorithms have a classification problem since there is often a stagnation when a certain level is reached, this was solved by different networks in various ways e.g., the ResNet uses skip connections. The VGG and AlexNet on the other hand have many parameters (> 50 million). Both are excellent algorithms for classification, but they are more difficult to handle than GoogleNet, which has reduced the parameters to 4 million [64].

The Resnet, the VGG architecture as well as the AlexNet were frequently used (**Figure 2**). These deep networks even achieved in ImageNet Challenge (ILSVRC) Competition History the best results for image classification (2015: ResNet; 2014: GoogLeNet and VGG-16; 2012: AlexNet) [62]. ResNet and GoogLeNet also performed well in the evaluation for H. pylori infection [63]. Thus, those studies tend to support our main finding that the above-mentioned algorithms stand out as excellent classifiers.

Another interesting performance evaluation in this study consisted of comparing the detection accuracy of the algorithms between CXR and Chest CT. Specified values of F1-Score and accuracy of algorithms applied on these imaging modalities were resumed respectively in 2 boxplots. From this comparison, it emerges that algorithms applied on chest CT present a better performance than those trained on CXR. This conclusion is based on the F1-score metric represented in the boxplot (**Figure 4**). Since the False Negatives are very crucial for the detection of the COVID-19 infection – There is a need to ensure that patients who are effectively affected are not reported as negative and thus deprived of care – the F1-score proves to be the most suitable and reliable metric to assess the detection performance in this case. Furthermore, in most real-life classification problems (as in the included studies), imbalanced class distribution exists and thus F1-score is a better metric to evaluate the model. For those reasons, the F1-score has been chosen over the accuracy metric to evaluate the performance of CXR compared to CT for detection of COVID-19. Lajarin V. et al [60] and Islam N. et al [61] found out chest CT scans to perform better than CXR on detecting the COVID-19 and therefore confirmed this finding.

Classification algorithms for pattern recognition and discrimination problems are commonly considered as "black boxes". Hence, considering all possible risk factors and transfer functions in an algorithm is a difficult and enormously time-consuming procedure. Optimizing all possible approaches would take more than several months.

The performance of the analyzed algorithms should therefore not be relied upon completely.

Regardless of the high discriminatory performance observed in most algorithms, there are major limitations and methodological deficiencies in the enrolled studies. Therefore, the present meta-analysis should be carefully interpreted. The limitations include:

- The included articles assessed deep learning diagnostic accuracy in a manner that does not strictly reflect clinical practice, because they were not compared with the performance of health-care professionals. Therefore, this is a major barrier to translate these results to the clinic.
- Not all included studies reported the TP, FP, FN, TN values and the confidence interval required to assess the sensitivity and specificity of the algorithms in the forest plots. Thus, some algorithms were not included in the plot and could not be analyzed.
- In situations such as the coronavirus disease (COVID-19) outbreaks, scientific research needs to be made available to the public as soon as possible to allow for rapid prevention and treatment. The necessity to share research results promptly has created a new trend known as preprints. Therefore, many articles about the COVID-19 are not peer-reviewed yet, but some of them were included in this study since they could report important data for our analysis. However, these cannot be totally and automatically trustworthy as they did not undergo peer review and could be subject to major changes after peer review is completed. Furthermore, mistakes in data and analysis of such articles could be encountered, which is associated with some risks for the interpretation of this meta-analysis.

V. CONCLUSION

Different networks were systematically analyzed based on various quality criteria. In this way, we found out which networks perform well and were able to identify similarities. Outstanding results have already been achieved with the frequent networks, and new approaches have also achieved excellent results. The new approaches reflect the “No Free Lunch” theorem, that there is no perfect algorithm for every problem. In addition to the frequently used networks, we should also always look for new approaches and evaluate them with different quality criteria to gain a comprehensive insight.

Appendix and the use of Supplemental files

Autor, year	TP	FP	FN	TN	DataSize	DL Methods	Accuracy	Sensitivity	Specificity	F1Scores	Class
O. Gozes et al, 2020 [1]	N/S	N/S	N/S	N/S	1865	ResNet-50	N/S	0.98	0.92	N/S	2
L. Li et al, 2020 [2]	N/S	N/S	N/S	N/S	4356	ResNet-50	N/S	0.90	0.96	N/S	3
J. Chen et al, 2020 [3]	N/S	N/S	N/S	N/S	3535	normal CNN	0.99	0.94	0.99	N/S	2
S. Wang et al, 2020 [4]	N/S	N/S	N/S	N/S	5372	DenseNet-121	0.78	0.80	0.77	0.77	2
S. Yang et al, 2020 [5]	N/S	N/S	N/S	N/S	295	DenseNet	0.95	0.97	0.87	0.93	2
C. Jin et al, 2020 [6]	N/S	N/S	N/S	N/S	9025	Individual Deep Net	N/S	0.87	0.97	N/S	4
	N/S	N/S	N/S	N/S			N/S	0.78	0.94	N/S	3
S. Ying et al, 2020 [7]	N/S	N/S	N/S	N/S	1990	VGG-16	0.84	0.89	N/S	0.84	2
	23	7	1	26		DER-Net	0.86	0.96	N/S	0.87	2
	N/S	N/S	N/S	N/S		DenseNet	0.82	0.93	N/S	0.83	2
	N/S	N/S	N/S	N/S		ResNet	0.86	0.93	N/S	0.86	2
C. Butt et al, 2020 [8]	N/S	N/S	N/S	N/S	618	ResNet	0.87	0.87	N/S	0.84	3
S. Wang et al, 2020 [9]	N/S	N/S	N/S	N/S	1065	normal CNN	0.79	0.67	0.83	N/S	2
X. Mei et al, 2020 [10]	N/S	N/S	N/S	N/S	905	normal CNN	N/S	0.84	N/S	N/S	2
C. Zheng et al, 2020 [11]	N/S	N/S	N/S	N/S	1283	DeCoVNet	0.90	0.91	0.91	N/S	2
Q. Xi et al, 2020 [12]	N/S	N/S	N/S	N/S	4982	ResNet-34	0.88	0.87	0.90	0.82	2
X. Wang et al, 2020 [13]	N/S	N/S	N/S	N/S	542	DeCoVNet	0.90	0.91	0.91	N/S	2
M. Kuchana et al, 2020 [14]	N/S	N/S	N/S	N/S	929	Attention Unet	N/S	N/S	N/S	0.97	2
M. Loey et al, 2020 [15]	73	13	21	92	742	ResNet-50	0.83	0.78	0.88	0.80	3
S. A. Harmon et al, 2020 [16]	N/S	N/S	N/S	N/S	3853	DenseNet-121	0.91	0.84	0.93	N/S	2
Y. Yang et al, 2020 [17]	N/S	N/S	N/S	N/S	185	ResNet-50	0.91	0.92	0.91	N/S	3
Y. Zhang et al, 2020 [18]	N/S	N/S	N/S	N/S	282	Individual Deep Net	0.94	0.93	0.94	N/S	2
K. Purohit et al, 2020 [19] *	2467	123	293	2637	690	ResNet-50	0.96	0.97	0.95	0.96	2
S. Ahuja et al, 2020 [20]	95	1	0	71	746	ResNet-18	0.99	1.00	0.99	0.99	2
	95	2	0	70		ResNet-50	0.99	1.00	0.97	0.99	
	93	3	2	69		ResNet-101	0.97	0.98	0.96	0.97	
	91	4	4	68		SqueezeNet	0.95	0.96	0.94	0.96	
H. Panwar et al, 2020 [21]	142	7	9	162	2482	Individual Deep Net	0.95	0.94	0.96	0.95	2
S. Sharma et al, 2020 [22]	200	43	17	400	2200	Individual Deep Net	0.91	0.92	0.90	0.87	2
D. Singh et al, 2020 [26]	58	9	10	55	N/S	ANN	0.86	0.85	0.86	0.86	2
	59	10	9	54		ANFIS	0.86	0.87	0.84	0.86	
	60	8	9	56		normal CNN	0.87	0.87	0.88	0.88	
	62	7	6	58		Individual Deep Net	0.90	0.91	0.89	0.91	
Z. Han et al, 2020 [24]	43	0	0	64	460	Individual Deep Net	1.00	1.00	1.00	1.00	3
	46	1	1	46			0.98	0.98	0.98	0.98	2
	43	0	0	64		C3D	1.00	1.00	1.00	1.00	3
	46	1	2	45			0.97	0.96	0.98	0.97	2
	43	0	0	54		DeCoVNet	1.00	1.00	1.00	1.00	3
	46	1	2	45			0.97	0.96	0.98	0.97	2
V. Shah et al, 2020 [25]	32	2	2	37	812	VGG-19	0.95	0.94	0.95	0.94	2
	28	6	7	32		Ctnet-10	0.82	0.80	0.84	0.81	
	32	4	4	35		VGG-16	0.89	0.89	0.90	0.89	
	31	2	3	37		DenseNet-159	0.93	0.91	0.95	0.93	
	5	0	29	39		ResNet-50	0.60	0.15	1.00	0.26	
	0	0	34	39		Inception V3	0.53	0.00	1.00	0.00	
U. Ozkaya et al, 2020 [23]	213	100	1	306	2492	VGG16	0.84	1.00	0.75	0.81	2
	216	97	0	307		ResNet-50	0.84	1.00	0.76	0.82	
	206	107	5	302		GoogleNet	0.82	0.98	0.74	0.79	
	196	117	1	306		DenseNet-201	0.81	0.99	0.72	0.77	
	288	12	25	295		CSVM	0.94	0.92	0.96	0.94	
H. Gunraj et al, 2020 [27]	4229	13	117	16832	104009	COVIDNet-CT	0.99	0.97	1.00	0.98	3

Table 1*: Overview of included articles based on chest CT dataset (n=26)*

N/S: Not specified. 2: Classification into COVID-19 or non-COVID-19; 3: Classification into COVID-19 or non-COVID-19 or other pneumonia; 4: Classification into COVID-19, non-COVID-19, bacterial pneumonia or viral pneumonia

**: Paper training both chest CT and CXR datasets (n=1); red: Preprint*

Autor, year	TP	FP	FN	TN	DataSize	DL Methods	Accuracy	Sensitivity	Specificity	F1Scores	Class
R. Jain et al, 2020 [28]	82	3	4	876	6432	Inception V3	0.96	0.95	1	0.95	3
	79	1	7	878		Xception	0.9797	0.92	1	0.96	
	67	2	19	877		ResNeXt V3	0.93	0.78	1	0.9	
K. H. Shibly et al, 2020 [29]	192	3	8	28	5450	faster CNN	0.9736	0.9765	0.9548	0.9846	2
M. Loey et al, 2020 [30]	N/S	N/S	N/S	N/S	306	AlexNet	0.6667	0.6667	N/S	0.6566	4
	847	5	7	1707		AlexNet	0.8519	0.8519	N/S	0.8519	3
	854	0	7	849		AlexNet	1	1	1	1	2
	N/S	N/S	N/S	N/S		GoogleNet	0.8056	0.8056	N/S	0.8232	4
	847	31	0	1681		GoogleNet	0.8148	0.8148	N/S	0.8146	3
	853	1	0	856		GoogleNet	1	1	1	1	2
	N/S	N/S	N/S	N/S		ResNet-18	0.6946	0.6667	N/S	0.6946	4
	851	0	3	1712		ResNet-18	0.8148	0.8148	N/S	0.8466	3
	853	1	2	854		ResNet-18	1	1	1	1	2
A. Abbas et al, 2020 [31]	N/S	N/S	N/S	N/S	196	AlexNet	0.9381	0.9173	0.903	N/S	3
	N/S	N/S	N/S	N/S		AlexNet+DeTraC	0.9566	0.9753	0.9349		
	N/S	N/S	N/S	N/S		GoogleNet	0.9368	0.9259	0.9152		
	N/S	N/S	N/S	N/S		GoogleNet+DeTraC	0.9471	0.9788	0.9576		
	N/S	N/S	N/S	N/S		VGG-19	0.9459	0.9164	0.9308		
	N/S	N/S	N/S	N/S		VGG-19+DeTraC	0.9735	0.9823	0.9634		
	N/S	N/S	N/S	N/S		ResNet	0.925	0.6501	0.943		
	N/S	N/S	N/S	N/S		ResNet+DeTraC	0.9512	0.9791	0.9187		
	N/S	N/S	N/S	N/S		SqueezeNet	0.9224	0.9504	0.8861		
	N/S	N/S	N/S	N/S		SqueezeNet+DeTraC	0.949	0.957	0.9471		
M. S. Boudrioua et al, 2020 [32]	61	1	1	602	3309	DenseNet-121	0.9428	0.984	0.998	0.991	3
	62	3	0	600		NASNetLarge	0.9218	1	0.995	0.974	
	61	4	0	599		NASNetMobile	0.9489	1	0.993	0.9652	
M. K. Pandit et al, 2020 [33]	N/S	N/S	N/S	N/S	1428	VGG-16	0.96	0.9727	0.9264	N/S	2
	N/S	N/S	N/S	N/S		VGG-16	0.9253	0.951	0.9867		3
S. Asif et al, 2020 [34]	N/S	N/S	N/S	N/S	3550	Inception V3	0.96	N/S	N/S	N/S	3
G. Jain et al, 2020 [35]	N/S	N/S	N/S	N/S	1215	ResNet-101	0.9722	0.9714	0.9714	0.9717	3
A. Z. Khuzani et al, 2020 [36]	25	1	0	59	420	Individual Deep Net	0.94	1	0.98	N/S	3
H. Panwar et al, 2020 [37]	41	9	1	33	284	NCOVnet	0.88	0.9762	0.7857	N/S	2
S. Vaid et al, 2020 [38]	33	3	1	72	364	Individual Deep Net	0.963	0.97	0.96	0.958	2
M. Elgendi et al, 2020 [39]	N/S	N/S	N/S	N/S	4350	DarkCovidNet	0.9428	N/S	N/S	N/S	3
K. Purohit et al, 2020 [19] *	527	5	6	531	134	ResNet-50	0.9619	0.9291	0.9944	0.96	2
A. Makris et al, 2020 [40]	24	0	2	42	509	VGG-19	0.9503	0.92	1	0.96	3
K. Ahammed et al, 2020 [41]	272	13	12	558	1764	Individual Deep Net	0.9403	0.9403	0.9701	0.9403	2
M. Nour et al, 2020 [42]	N/S	N/S	N/S	N/S	2905	DarkCovidNet	0.8702	0.9218	0.8996	N/S	3
	N/S	N/S	N/S	N/S		COVIDiagnosis-Net	0.9826	0.9913	N/S		
	N/S	N/S	N/S	N/S		COVNet	0.9264	0.9137	0.9576		
	N/S	N/S	N/S	N/S		ResNet-50	0.98	N/S	N/S		2
	N/S	N/S	N/S	N/S		DER-Net	0.86	0.96	N/S		
	N/S	N/S	N/S	N/S		Inception	0.895	0.87	0.88		
	N/S	N/S	N/S	N/S		nCOVnet	0.881	0.9762	0.8913		
	59	2	7	804		Individual Deep Net	0.9897	0.8939	0.9975		3
Md. Z. Islam et al, 2020 [43]	41	9	1	33	4575	Individual Deep Net	0.985	0.982	0.99	0.977	3
	305	2	0	608		proposed mit LSTM	0.992	0.992	0.993	0.989	
M. Y. C. Azemin et al, 2020 [44]	119	1646	35	4182	5982	ResNet-101	0.773	0.718	0.719	N/S	2

Table 2: *Overview of included articles based on chest X-ray dataset (n=17)*

N/S: Not specified. 2: Classification into COVID-19 or non-COVID-19; 3: Classification into COVID-19 or non-COVID-19 or other pneumonia; 4: Classification into COVID-19, non-COVID-19, bacterial pneumonia or viral pneumonia

**: Paper training both chest CT and CXR datasets (n=1); red: Preprint*

LIST OF ABBREVIATIONS

AUC	Area under Curve
C3D	Convolutional 3-dimensional Network
CNN	Convolutional Neural Network
COVID-19	Coronavirus disease 2019
COVNet	Detection Neural Network
CT	Computed tomography
CXR	Chest X-ray
DenseNet	Dense Convolutional Network
DeTrac	Transfer Learning of Class Decomposed Medical Images in Convolutional Neural Networks
FN	False Negative
FP	False Positive
LSTM	Long Short-Term Memory
NASNet	Neural Architecture Search Network
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
ResNet	Deep residual network
RT-PCR	Reverse transcription polymerase chain reaction
SROC	Summary receiver operating characteristics
TN	True Negative
TP	True Positive
VGG	Visual Geometry Group

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Advancements and Usage of Telemedicine in Times of the COVID-19 Pandemic - Systematic Comparison of Developments and Contributing Factors in European Countries

Daniel Bleher, Sebastian King, and Philipp Goos

Abstract—**The fast spread of the current COVID-19 pandemic can overburden health care facilities all over the world. To slow down the spread of the virus, many countries put restrictions on public life. Personal contacts have to be reduced as far as possible to avoid contact to infected people. Telemedicine offers the opportunity to deliver health care services over distance without the need for in-person contacts. It can therefore be a useful tool during the current pandemic. The usage of telemedicine increased rapidly after the start of the pandemic, but the developments varied from country to country. We conducted a literature review on the development of telemedicine in six different European countries: Germany, France, Norway, Spain, Italy, and the Netherlands. We also looked at the pandemic situation and the health care systems in the selected countries to find contributing factors for these differences. In all countries, we found some advancements in the use of telemedicine. Most of them adjusted regulations to allow more reimbursement of telemedicine services as they considered it to be critical to ensure delivery of health care services. In Italy, although being severely affected by the pandemic, developments in the field of telemedicine have been rather slow and differed from region to region. This might be due to its highly decentralized health care system making a national approach rather difficult. However, studies in all examined countries emphasize the importance of telemedicine during the pandemic.**

Index Terms—**COVID-19 pandemic, health care systems, telemedicine, video consultations**

I. Introduction

THE World Health Organization declared the COVID-19 outbreak a pandemic on March 11, 2020 [1]. The pandemic led to severe challenges for health care systems and particularly health care providers in many countries all over the world. The rapid increase in patients needing hospitalization may exceed hospitals' capacities. To slow down the spread of the virus, many countries put restrictions on public life or issued guidelines to reduce personal contacts. This led to a rapid shift towards the use of new technologies like online learning and telemedicine [2]. As the severity of the pandemic is different in every country, lockdown regulations and technological developments differ greatly in different countries. Bhaskar *et al.* [3] examined the implementation of telemedicine in different countries and issued recommendations for the improvement of telemedicine services in these countries. Fisk *et al.* [4] specifically focused on developments in the United States of America, Australia, and the United Kingdom. However, a comparison of the developments in different European countries is still missing. For this reason, we wanted to take a closer look on developments and specific projects in certain European countries to find possible explanations for these differences. Therefore, we also investigated the pandemic situation and the type of health care system in these countries.

A. *Telemedicine*

The term telemedicine describes the delivery of health care services over distance using information and communication technology [5]. Telemedicine can be used for consultation, diagnosis, treatment, and follow-up. It may also be used for consultation between different health care professionals. Telemedicine is suitable for situations where physical contact is not necessary or not possible because health care professionals and patients are far away from each other (e.g., patients in remote areas or on ships at sea).

In the current COVID-19 pandemic, reducing personal contacts is paramount to slow down the spread of the virus. Telemedicine can be a helpful tool to reduce the risk of possible exposure to infected persons at hospitals or doctors' offices for both patients and health care professionals [6]. That is why the development of telemedicine is of great importance, especially during the current pandemic, but also to be prepared for future challenges to the health care system.

Telemedicine can be delivered synchronous, meaning live, (e.g., telemonitoring or teleconsultation) or asynchronous, meaning storing recorded data and sending it later (e.g., store and forward of medical data or images).

B. *Health care systems*

The structure of health care systems differs widely in different countries. Böhm *et al.* [7] classified health care systems by analyzing three defining core dimensions:

regulation, financing, and service provision. Then, they named three types of actors in these dimensions: state actors, societal actors, and private actors. Following this structure, the authors categorized the health care systems of OECD (Organisation for Economic Co-operation and Development) countries. They found six main clusters of countries with the following health care systems. In a National Health Service (e.g., Norway, Spain) the state is the principal actor in all three dimensions. In a National Health Insurance (e.g., Italy) services are provided by private actors but regulation and financing are done by the state. The social-based mixed-type exists only in Slovenia where societal actors do regulation and financing and the state delivers health care services. Countries like Germany and Austria have a Social Health Insurance with societal actors in regulation and financing, and private actors in service provisioning. The authors named the combination of state regulation, societal financing, and private provisioning an Etatist Social Health Insurance. It is present in many countries, e.g., the Netherlands and France. The United States of America have a Private Health System. Although there are some state initiatives like Medicaid and Medicare, private actors largely dominate all three dimensions.

II. Methods

At the beginning of the research a literature review was done. For that purpose, the PubMed database, which is the most popular database for biomedical and life sciences literature, was used. Therefore, a specific search query was being used. The search was done for papers with the keyword “Telehealth”, “eHealth” or “Telemedicine” in the title or the abstract. The next essential keyword was “Covid” or a similar name for the virus. In order to find studies for the desired country, the country name was searched in the full text. For ensuring to find only recent papers published during the Covid-19 pandemic, a filtering for papers with a publication date after January 1, 2020, was done. After that, the found papers were filtered manually by the authors.
The exact search query used is shown below.

*((Telehealth[Title/Abstract]) OR (Telemedicine[Title/Abstract]) OR (eHealth[Title/Abstract])) AND ((SARS-CoV-2[Title/Abstract]) OR (Covid[Title/Abstract])) AND (("2020/01/01"[Date - Create] : "3000"[Date - Create])) AND ([**Placeholder for a country]** [Text Word])*

In addition, due to the topicality of the subject, trustworthy Internet sources (from official institutes, ministries) were used.

The research does not claim to find every single detailed source, as a basic comparison of the main measures in the individual countries is made.

The selection of countries for the investigation depends on the following aspects:

- No detailed analysis in one of the two found country comparison papers
- Search yield of literature
- Health care system of the country
- Current COVID-19 situation
- European country

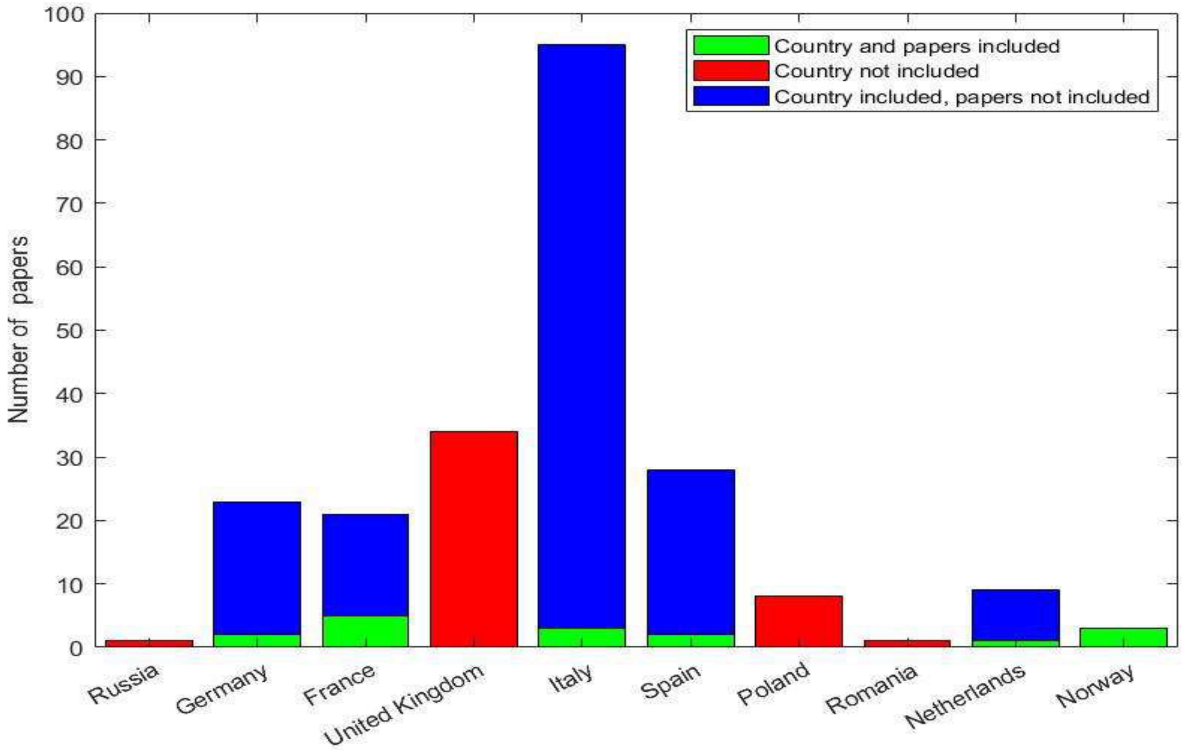

Figure 1. Found papers with search query for European countries

After considering these points, the following countries were selected:

- Germany
- France
- Norway
- Spain
- Italy
- Netherlands

Compared to all other European countries, the search yield of the literature was most promising for these six countries. The search results for some of the most populous European countries, including the selected six, are illustrated in Figure 1. Using the search query shown above, 23 sources were found for Germany, 21 for France, 3 for Norway, 28 for Spain, 95 for Italy and 9 for the Netherlands. Divided by health care system, Spain and Norway represent the National Health Service. France and the Netherlands rely on an Etatist Social Health Insurance. Italy has a National Health Insurance. Germany's health care system is a Social Health Insurance. Thus, with the exception of the private health system, which only exists in the US, all the main types are represented [7]. Furthermore, despite geographic and social proximity, the incidence of infection differs greatly across Europe [8]. For this reason, it was ensured that both highly affected countries with a high incidence, such as Netherlands, Spain, France and Italy, and moderately and little affected countries, such as Germany and Norway, were analyzed. But incidences per se are not very meaningful without including mortality rates. To show how strongly the rates vary in Europe, countries with high, medium and low mortality rates were included [9]. Italy, Spain and France have enormously high mortality rates, whereas Netherlands, Germany and Norway have medium to low mortality rates. These important values are shown in Figure 2.

After the research, a comparison of telemedical measures before and in the pandemic has been done for each country.

III. Results

A. COVID-19 Situation on December 31, 2020

To get a better understanding of the impact of the pandemic on the different countries and to make the numbers comparable, we did not only look at the absolute numbers of infections and deaths but also at the relative numbers. Therefore, we compared the number of confirmed infections and confirmed deaths per 100.000 inhabitants as seen in Figure 2.

1) Germany

In Germany, the first COVID-19 outbreak was observed at the end of January. The virus became a noticeable problem on February 01, 2020 [10]. Furthermore, compared to the other European countries, Germany´s infection rates did not increase explosively. Until December 31, 2020 Germany had 1,741,153 confirmed infections and 33,230 deaths. With a case-fatality ratio (number of deaths divided by the number of infections) of 1.9 % and a death rate (deaths per 100 thousand inhabitants) of 40.07, Germany has some of the lowest rates in Europe [9].

2) France

France was one of the most severely affected countries during the COVID-19 pandemic. Until December 31, 2020, France has had 2,657,624 confirmed infections with SARS-CoV-2 and 64,508 related deaths. The case-fatality ratio is at 2.4%. The number of deaths per 100,00 inhabitants is 96.30 [9].

3) Norway

Until December 31, 2020, Norway confirmed 49,010 infections with SARS-CoV-2 and 436 related deaths resulting in a case-fatality ratio of 0.9%. The country only had 8.20 deaths per 100.000 inhabitants [9].

4) Spain

With the first COVID-19 infection on February 25, 2020, the pandemic started in Spain [11]. Infection and mortality rates rose at a rapid pace. Until December 31, 2020, there have been

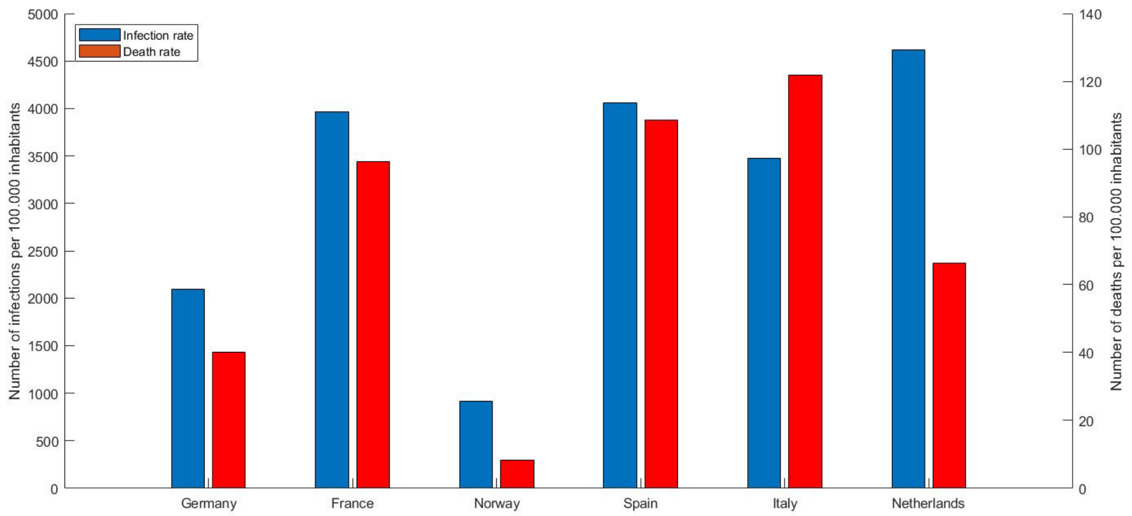

Figure 2. Compared Rate of SARS-CoV-2 Infections and Deaths per 100.000 inhabitants

1,910,218 infections and 50,689 cases of death in Spain. With a case-fatality ratio of 2.7% and a death rate of 108.49, Spain is considered one of the most affected countries worldwide [9, 11].

5) Italy

Italy has also been one of the most affected countries by COVID-19 earlier in 2020 and is being hit hard by the second wave with 2,083,689 infections and 73,604 deaths (121.80 per 100,000 inhabitants) to date (December 31, 2020) [12]. The case-fatality ratio is at 3.5% in Italy.

6) Netherlands

In relation to the number of inhabitants, the Netherlands are also highly affected by the pandemic with 798,592 confirmed infections and 11,417 deaths (66.26 per 100.000 inhabitants) [9]. In the Netherlands, the case-fatality ratio is at 1.4%.

B. Healthcare Systems

1) Germany

Like all German speaking Countries, Germany has a Social Health Insurance system [7]. This means that the regulation and the financing are societal, and the service provision is private. Almost 100% of Germans have a health insurance. Round about 90% (75 Mio people) are covered by statutory, state-funded health insurance. This statutory health insurance system is one of the largest in the world. The remaining 10% are privately insured [13]. "The costs of this healthcare system are high (…) over one in ten euros of Germany's GDP goes on healthcare." [14] The German health care system is based on five principles. The first one is the "mandatory insurance". The second one: "Financed by contributions principle" means, that the social health insurance and the private health insurance both are financed by contributions or premiums from their members. The personal income is decisive for the amount of the contribution. The "solidary" principle implicates that the financing of the system is solidary. All bear the costs for an individual [14]. "So the healthy pay for the sick, the rich for the poor and singles for families." [14] Next principle is the "No direct payment by patients" principle. Every insured person has the right to free treatment. The self-administration is the last principle, which means that the system is coordinated by the involved. The role of the state is to define a framework for medical care by enacting laws and regulations.

2) France

The healthcare system in France is largely financed by the government run national health insurance. It includes every citizen and legal resident of France. For health care services, three types of cost-sharing are applied: coinsurance, copayment, and extra billing. The national health insurance reimburses different rates of health care costs depending on the type of health care service, e.g., 80% for hospital care and 70% for doctor visits. The remaining costs can be covered by a complementary private health insurance. Additionally, certain copayments apply e.g., for days in hospital, doctor visits, and prescription drugs. These copayments are not reimbursable, neither by the national health insurance, nor by private health insurances. Finally, doctors may charge more than the reference price imposed by the national health insurance. Patients must pay the amount exceeding this reference price on their own as it will not be covered by insurance [15].

3) Norway

The healthcare system in Norway is a national health service completely run by the state. It covers all health care costs for children aged sixteen or younger and certain other groups like retirees. All other adults have to pay annual deductibles and costs exceeding these deductibles are covered by the state. The universal coverage is meant to ensure equal access to health care for all residents. Most hospitals are public hospitals run by four Regional Health Authorities under the Ministry of Health and Care Services. Few residents are enrolled in private health insurances. They may offer shorter waiting times for health care services [15]. In 2019, Norway spend 10.5% of their GDP on health care [16].

4) Spain

Like Portugal, England and Sweden, Spain has a National Health Service system [7]. As usual in such health care systems, it´s freely accessible, equitable and the financing is based on tax money. Moreover, the Spanish health care system is highly decentralized. The state has to shape health policy, while the regional Autonomous Communities (ACs) are responsible for providing health services [17]. In this system the state regulates the relationship between the main actors in health care (regulation, financing and provision) [7]. Compared to similar countries, the Spanish health care system is generally well positioned in almost all dimensions: population coverage, global equity, equity of access, technical quality and economic efficiency [18]. Like Germany, Spain owns private and public systems in which 100% of the Spanish population has the opportunity to access the public system [19]. "All these characteristics have a great consensus and social support, only clouded by the surprisingly low priority that health (…) have on the Spanish political agenda." [18]

5) Italy

Looking into the Italian healthcare system, it will be seen, that it consists of a national health insurance, which means that healthcare is mainly funded by taxes. Therefore, patients can access health services free or almost free of payment. In the context of telehealth, the Italian national healthcare service does not do much for patients, because it does not consider telemedicine as an essential level of care [20]. This problem is further emphasized by the regional structure of the healthcare system, which puts local authorities in charge of providing health services [21], which leads to a lack of national guidance and regional differences in the distribution of telemedicine.

6) Netherlands

In 2006, the Dutch government implemented a major reform of the health care system to deal with the rising costs of the old system [22]. Health insurance became mandatory for all residents. Because of the high number of orthodox Calvinists and Evangelic Christians who refuse to sign up for health insurance, there is an exemption of the mandate for those with conscientious objections [15]. Regulation is done by the state, but all health insurances operated independently. Insurances receive compensation for high-risk patients through a risk equalization pool. All insured pay the same price for their selected health care plan with a certain annual deductible. Children until the age of 18 do not pay deductibles. Adults can choose to pay higher deductibles for lower monthly premiums.

C. Comparison of telemedicine pre-COVID-19

The COVID-19 pandemic changes the way and extend to which telemedicine is being used. Regarding telemedicine in the six examined countries, it will be seen that regulations and measures differ vastly even though all countries are geographically close to each other and part of the European Union.

The Netherlands provide a good example for telehealth in Europe next to the Nordic Countries. The Annual European eHealth Survey 2019 [23] named said countries as role models for eHealth innovation in Europe. This is backed by the efforts of the Dutch government to encourage the use of eHealth in the 2010s [24]. Their goals included the access to their own medical records for patients, especially for the chronically ill. Another measure for the chronically ill, but also elders, pursues the ability to monitor some vital parameters and pass them on to a healthcare provider.

Innovation is another important aspect of telehealth that is covered by the Dutch healthcare program. The Dutch government therefore provides support for the development of new ideas and applications, as well as information about the funding of projects. Furthermore, a startup network, that focuses on sharing knowledge in the field of telehealth among healthcare providers, patients, and lawyers, has been established, to advance innovations.

Germany determined their telematic infrastructure earlier than the Netherlands in 2004 by introducing the Healthcare Modernization Act (Gesundheitsmodernisierungsgesetz), which set the foundation for the electronic health card (eGK). Telemedicine was embraced further by the " Gesetz für sichere digitale Kommunikation und Anwendungen im Gesundheitswesen“ (E-Health-Law) in 2016, which led to an increasing number of telemedicine applications [25].

In terms of reimbursement for the use of telemedicine, major differences were present in the countries. Prior to the pandemic, in January 2020, the Digital Healthcare Act (“Digitale-Versorgung-Gesetz” – DVG) came into force in Germany “just-in-time” [26] [13]. From this point on, patients no longer needed to pay for digital health application for themselves. The insurances will cover the costs. For this purpose, a regulation about what kind of digital health treatments is reimbursed by the insurances is required.

Other countries which covered most costs for telemedical treatments are Norway and the Netherlands. Contact via videoconference is equally reimbursable as a regular outpatient visit in Norway, but store-and-forward telemedicine is not [27]. In the Netherlands payment for medical appointments is made equivalent to regular payment, but only if special service was provided. Furthermore, health insurance companies may have restrictions regarding telemedicine in their contracts with practitioners.

The French national health insurance does not cover the costs for telemedicine fully. Although regulations allowed the use and reimbursement of teleconsultations with already known patients when suitable [28], there are examples for non-government paid telemedical services. In 2016, the service Deuxiemeavis.fr (Engl.: second opinion) was launched. Patients can upload their medical records and get a second opinion from a doctor. This second opinion is completely based on the patient’s medical record and no clinical examination is done. Although the service is not reimbursable by the national health insurance, some complementary private insurances may cover it [29]. Another example for a partially free service is the service Doctolib.fr, which was launched in 2013. Patients can use it to find information about the services different doctors offer and book appointments with them. Doctors can use it to manage their appointments. The service is free for patients. Doctors must pay a monthly subscription fee. Since 2019, Doctolib.fr has also been offering a video consultation service.

Italy presents a healthcare system, which does not consider telemedicine as an essential level of care [20], and therefore did not cover any costs for its use. Even though national telemedicine guidelines had been implemented in 20 regions of Italy since 2018, hospitals are not doing well in the field of telemedicine. On March 23, it was mentioned that hospitals are lacking required hardware, technical resources as well as sufficient bandwidth capacities, but also problems due to the high workload of IT staff were addressed [30].

Spain and Italy both suffer from the regional structure of their healthcare systems. It is stated that Spain “lacks a national telemedicine policy, which is required for the development of nation-wide effective telemedicine strategies” [3]. As a result, the establishment of eHealth programs varies from region to region. Catalonia, for example, “with roughly 7.5 million inhabitants, (…) has been considered a forerunner of eHealth adoption in Europe.” [11] However, other regions are lagging far behind.

Nonetheless, Spain did establish eHealth more and more [17]. The possibility of making appointments online with your general practitioner or paediatrician is widespread throughout the country. Nevertheless, the use of this function also differs from region to region. Important factors for the acceptance of such applications include a young age, a high level of education and a fast internet connection. As a result, the number of users in cities is higher than in more rural regions [17].

Also, there are electronic prescriptions at a similar level. This is also widely used in primary care and emergency care. In secondary care, these functions do not exist yet across the board [17].

In radiology, digitized images are standard. In other areas such as pathology, traditional diagnostic methods are still used the most. With digital images, diagnosis can be done independent of location. Teleconsultation and remote diagnostics become possible [17].

Next to Spain, other countries accelerated the development of telemedicine in recent years. In the years before the pandemic, there were many telemedical projects in Germany. In 2015, for example, there were about 200 active projects. But the problem manifests itself in the rare use of them. The projects are often isolated solutions which are not used nationwide and they lack in interoperability [31]. Additionally, exclusive treatment via communication media was prohibited in Germany until 2018. With the abolition of the remote treatment prohibition, it was possible to loosen the regulations and an exclusive remote treatment was made accessible in special cases [32].

The use of telemedicine in Norway before the COVID-19 pandemic, despite being widely adopted in many hospitals, was still very low compared to regular outpatient visits [27] but still increased over the last years. Norway has a long history of telemedicine. Medical guidance via telephone was already being delivered since 1949 to ships at sea. Also, hospitals support oil platforms in medical emergencies via videoconferences and transmission of biological parameters [27].

D. Comparison of telemedicine during-COVID-19

Despite the geographical and social proximity, the individual situation, the health insurance systems, and the regulations regarding telemedicine differ massively in the European countries. This leads to different telemedicine measures being established in different countries to combat the pandemic.

1) Germany

So far, the COVID-19 pandemic has been "a catalyst for telemedicine services in Germany."[26] The National Association of Statutory Health Insurance Physicians (KBV), for example, has quickly removed the limits and barriers to telemedicine, due to the danger of the COVID-19 virus [26]. Therefore, unnecessary contacts should be avoided. To achieve this, they have made video consultations much more accessible to physicians and they have removed restrictions on video consultations with psychotherapists. Furthermore, they have created the possibility of e-sick notes. This allows patients to receive their sick note without having to see a doctor personally.

The newly created facilities are also accepted by the population.

In addition to the population, healthcare workers also consider telemedicine to be useful in fighting the pandemic. This was shown by Peine et. al. [33] in a survey of 2730 people from the healthcare sector. According to the survey 39% considered telemedicine to be very important in the pandemic. 20.8 % even consider the role to be very high. 26.4% regard the role of telemedicine as rather neutral.

At the moment the demand for video consultations is constantly increasing. In addition, a number of useful telemedicine applications that can contribute to the fight against the pandemic have been created throughout Germany [26]. With the Ada project for example, a corona triage solution was achieved. Furthermore, the Charité in Berlin has developed a COVID-19 app (CovApp), which provides recommendations for actions and information about the coronavirus.

2) France

An important factor for increased and widespread use of telemedicine interventions is reimbursement. In response to the COVID-19 pandemic, the French Ministry of Health allowed reimbursement of consultations via telemedicine for patients with COVID-19 symptoms or confirmed infections without the need for an in person contact beforehand [28]. Additionally, the national health insurance now covers 100% of the costs of teleconsultations. Before these new regulations, only the regular rate of 70% was reimbursable [29]. Later on, follow up by nurses, midwives, and speech therapists through teleconsultations were also allowed [28]. The pandemic and these new regulations from the French government led to an exponential growth of video consultations from less than 10,000 per week before the pandemic to 486,369 during the second week of lockdown in March [34].

The Covid-19 pandemic is straining all areas of medicine and demands new solutions. Helissey *et al.* [35] evaluated the impact of the COVID-19 pandemic on medical practice in oncology. The study examined nine French hospitals. They found that 47.6% of included patients received modified care, e.g., postponed surgery. The authors also found a reduced number of newly diagnosed cases of cancer. As patients may avoid a visit to their general practitioners during the pandemic and screening programs are halted, many cancer patients may remain undiagnosed. The follow-up of 70% of patients were done via telemedicine. Accordingly, the authors stated that telemedicine now plays an important role in their care pathways and will do so in the future. Remaining limitations are the absence of clinical exams and the need for technological means that ensure communication quality, safety, and security.

Pinar *et al.* [36] analyzed French urology patients' and physicians' satisfaction with teleconsultations during the pandemic. Finding a high overall satisfaction with teleconsultation by patients and physicians, the authors also did not see differences in satisfaction between different age groups. Older patients were equally satisfied with teleconsultations as younger patients. However, there are still some points open to further improvements. Images from computed tomography scans or magnetic resonance images could not be exchanged between physician and patient. Furthermore, few patients experienced poor video quality that even led to some of them having to terminate the teleconsultation. The authors concluded that although teleconsultations will probably never be able to fully replace all in-person consultations, it is an acceptable option to access health care during the current pandemic and may also be used in the future.

Renard [37] described his experiences with diabetes care and how telemonitoring and teleconsultation can be successfully used during the COVID-19 pandemic. While playing no important role before the pandemic, telemedicine quickly became usual practice after the outbreak. Patients sent in downloaded data from their glucose monitoring and physicians could suggest adaptations to insulin pump settings. In case a patient needed assistance with downloading data, or the pump needed to be replaced, they could send an email to their home care providers and a nurse would come to help them. The author expects a positive impact of experiences gathered during the pandemic on future diabetes care. Despite being expensive, these technologies proved to be a good investment especially during these difficult times.

The pandemic and lockdown orders also affected clinical research. Takeda *et al.* [38] elaborate on how their clinical research center adapted its activities to comply with lockdown regulations. As in person consultations were only allowed in emergencies, recruitment for their study was temporarily interrupted. Therefore, patient visits for the cohort observational study were held via video consultations. Together with their recently launched monitoring app the authors were able to continue research during the lockdown period, and to restart in best conditions once the clinical research center was fully reopened after the end of lockdown.

3) Norway

After the start of the shutdown, there was a massive increase in online video consultations reported with most of the general practitioners in Norway being able to provide these online consultations [39].

Birkeland [40] described how the pandemic changed the delivery of health care services to diabetes patients at a Norway hospital. Most of the consultations were held via telemedicine and a telephone hotline was set up to answer the patients' questions. It received up to 150 incoming calls per day. Patients wearing continuous glucose monitoring started exploring the possibility of downloading the reports to their computers so they could better monitor their diabetes.

In another study, Kristoffersen *et al.* [2] examined the impact of the COVID-19 pandemic on hospital-based headache care in Norway and Denmark. They found that 88% of hospitals in Norway switched to primary telephone consultations for headache patients. 35% began offering video consultations. The authors stated that telemedicine can be a promising appointment option as treatment for non-acute headache patients does not necessarily require a full neurological examination [2]. Despite the usage of new technologies, the authors found that the number of new patients referred to the out-patient clinics decreased and the standard of headache care during the lockdown was worse than before. They concluded that more research on the implementation of telemedicine in headache care is needed.

4) Spain

In the course of the pandemic, there have been some innovations in the field of "eHealth" in Spain [3]. However, these innovations were only introduced in certain regions because of not having a common national COVID-19 eHealth strategy. In Spain the Autonomous Communities are responsible for the implementation of eHealth applications [17].

Successful hospitals are exposed to share their experiences and strategies with others [3]. Despite all this, the number of users of telemedicine apps is increasing. Many of these contain very good approaches to achieve a significant contribution to the fight against the virus. For example, "Spain's leading telehealth app, MediQuo, has now made consultations regarding COVID-19 free of charge." [3]

Pérez Sust P et al. [11] describes the advanced digital health strategy in Catalonia in times of pandemic. He refers that across all ACs, the region of Catalonia is considered as one of the most advanced regions in digital health and can be compared to other European countries. To avoid as many face-to-face contacts as possible, Catalonia has implemented a comprehensive digital strategy. The first step consists of simplifying access to Catalan Personal Health Folder ("My Health") by providing call centers and enabling self-registration. In addition, the functionality of My Health has been enhanced by allowing patients to obtain their sick leave certifications online [19]. The study Pérez Sust P et al. [11] also describes the expansion of Catalan's virtual visit system (eConsult), which is being used to dramatically reduce contact. With this expansion physicians can start a video consultation directly from the electronic medical record. These new methods of bringing healthcare to patients without contact are widely accepted in Catalonia. The classical medical face to face treatment or counselling decreased continuously from March 9 onwards. On the other hand, the demand for teleconsultation increases rapidly.

During a pandemic, healthcare staff is of great importance, which is why they have to be protected. In mid-August, 22% of healthcare staff were already infected with the SARS-CoV-2 virus [41]. For this reason, a web access for the EMRs (electronical medical records) was introduced in Catalonia to allow physicians to work from home [11].

In the case of a COVID-19 infection, it is highly important for doctors to know the development of symptoms when patients are forced to stay at home. A reporting service has therefore been set up [11].

The mental health of citizens is another critical point during a pandemic with lockdown periods. For this purpose, Catalans can visit a web portal that provides information and other assistance [11].

5) Italy

The Italian healthcare system is not considered a shining example in the use of telemedicine interventions [30]. Despite this, there have been some promising studies covering the usage of telemedicine. A study report by S. Negrini et al. [42] about the "feasibility and acceptability of telemedicine as a substitute for outpatient services in emergency situations such as the sudden surge of the COVID-19 pandemic" [42] achieved positive results, thus presenting telemedicine as a satisfactory way of reducing the risk for medical staff and the spread of COVID-19 within medical facilities. The study was conducted at a "tertiary outpatient rehabilitation institute for spinal deformities, specializing in pediatric health conditions"[42].

During the first wave of COVID-19, the hospital minimized all initial face-to-face services, which included e.g., consultations, physiotherapy, and psychological meetings. A plan has been designed and according to it patients between the ages of 3 and 18 were offered the telemedicine service. This service included communication via free teleconference apps like Skype or WhatsApp, tutorials, and physiotherapy learning sessions for parents. A control phase of 30 days before COVID-19, a 13-day phase during COVID without telemedicine services and a 15-day phase whilst using telemedicine services were analyzed in the study.

There has been a significant decrease of services from the control phase to the COVID-19 phase, which resulted from the fear of a COVID-19 infection. The number of services recovered during the telemedicine phase, where physicians and physiotherapists completed 1207 telemedicine services. This shows that the services were accepted by the patients. The practitioners were also satisfied with their work experiences.

Results of the study indicate that it is possible to at least reduce the number of missed visits by patients due to COVID-19 by utilizing telemedicine. Satisfaction amongst patients shows that Italy is in "an ideal experimental setting for telemedicine" [42].

Regarding the impact of COVID-19 on mental health services and its patients, an article was released by M. Percudani et al. [43]. This article describes the situation in Lombardy, the most heavily hit region in Italy. According to the article, the Regional Health Authority deemed mental health services as essential. Telemedical measures have been recommended to ensure the safety of patients and mental staff early in March. Psychological services are evaluating the urgency for measures, so that treatment for patients affected by serious mental disorders, social problems or judicial sentences is continued. Triage sessions are only conducted with the use of telemedicine to get a grasp of the urgency of a new patient.

Notably, the pre-described findings focused almost exclusively on the first phase of COVID-19. In the second phase telemedicine will continue to play a major role to ensure social distancing. Daniele Giansanti [44], from the Istiuto Superiore di Sanità, reflected on the role of telemedicine during the first phase but emphasizes the needed actions for the second phase. Therefore, he states that "[during] the first phase of the pandemic, we scholars had the opportunity to observe the impact of telemedicine during the emergency" [44]. He references several studies conducted for different patient demographics. These include patients with multiple chronic diseases, patients with rare diseases, patients who need tele-related visits as well as medical staff. The other two mentioned studies dealt with the possibility of enlarging telemedical services and with the telerehabilitation of COVID-19 patients. Giansanti concludes that the Italian healthcare system did miss an opportunity in the field of telemedicine so far, but also mentions, that "there is still a chance to reflect around [the previous efforts on telemedicine] and inspire models useful for the second phase" [44].

6) Netherlands

As a modern country, many telemedicine measures were used in the Netherlands even before the pandemic. But the COVID-19 virus calls for further measures. On March 17, 2020 the Dutch Healthcare Authority released a press statement, that covered measures to make the use of telemedicine available for all health practitioners [45]. To achieve this, the Dutch government expanded the possibilities of telemedicine by removing barriers and restrictive conditions in all medical fields. The rules apply until one week after the government removes their national guidelines for public health and environment. With the restrictions removed, it is, inter alia, possible to not see the patient face-to-face on the first meeting. Payment for medical appointments is made equivalent to regular payment, even though no special service was provided. Furthermore, the Authority urged health insurance companies to also remove all restrictions regarding telemedicine in their contracts with practitioners.

Telehealth solutions fit for COVID-19 patients or COVID-19 suspects are also implemented. An example for this is the so called COVID Box [46]. It provides a monitoring set consisting of a thermometer, pulse oximeter, blood pressure monitor and a safety bag for the return of the devices. The box aims to offer care for suspected COVID-19 patients and to reduce hospitalizations, as well as reducing the time spent in the hospital.

The protocol foresees, that patients, who received the box, monitor their vitals three times a day while quarantining. If the values fall out of a reference, the patient could call the national emergency number and inform the authorities. Physicians also offer COVID-19 consultation hours to check measurements and determine further actions. A support team assists all the processes from preparing the boxes to disinfecting after use and help patients with technical problems. In the first phase of the project, the vital parameters are entered manually by the physician during consultation. The devices are linked to an app via Bluetooth for automatic data collection in the final version. A pilot evaluation of 55 patients from March 1 to June 15 showed promising results.

IV. Discussion

This paper evaluates the previous situation and advancements of six different European countries in terms of the COVID-19 pandemic. It also covers the different healthcare systems in the considered countries and creates connections between these systems and the telemedicine measurements, that were taken.

The different spread of the COVID-19 virus leads to a different need for telemedicine. Higher numbers of infections set a higher risk for healthcare workers and therefore telemedicine may help as a tool to prevent contact of infected patients with healthcare workers or possibly infected healthcare workers with uninfected patients. Taking the number of infections per 100.000 inhabitants from Figure 2 into account, Norway had the least need for telemedicine, followed by Germany. Italy, France, and Spain had a greater need for telemedicine and the Netherlands showed the highest infection rates.

Expectations towards the European health care systems are high, given that the European region is highly developed, and its countries have some of the most social and expensive healthcare systems worldwide. Addressing the level of development in Europe, it is also surprising that two of the examined countries (Italy, France) reported problems with telemedicine due to insufficient hardware and internet connection.

The difference in prevalence of telemedicine pre COVID-19 may also be influenced by cultural differences among Europe. Northern countries, like Norway, the Netherlands or Germany, tend to be more distant emotionally and socially in comparison to southern countries like Italy [47]. This means that they do not value in person contact as much as the southern, which leads to the conclusion, that telemedicine measures are accepted better in the reserved countries. Nevertheless, research shows a significant increase in the acceptance of telemedicine throughout the population over the course of this year but especially in a younger audience and in urban areas as data from Spain suggests. This however does not indicate that elders are not using telemedicine at all or are not satisfied by the results. Studies in France and Italy showed that patients of all ages as well as doctors were satisfied with the use of telemedicine. Overall, the population's acceptance and usage of telemedicine increased greatly throughout this year.

All examined healthcare systems provide basic care to the whole population with no or only little charge. This also applies to telemedicine in most countries, at least in times of the COVID-19 pandemic. The French government for example and Spain's telemedicine app MediQuo made the previous chargeable teleconsultations completely cost free. Italy, as the outsider, does not include telemedicine in their level of essential care, and therefore patients or doctors would have to invest for teleconsultations. This is another reason that telemedicine was not well established in Italy pre COVID-19.

Several countries, like France or the Netherlands, reshaped their regulations for telemedicine in response to the pandemic. Both countries for example do not require an initial face to face consultation anymore. Germany has this same policy for initial contact but not only since the pandemic but since 2018. Regulations in Germany have not been adjusted much as a response to the virus, because there seems to be no need for changes, as regulations are already comparable to those implemented in other countries.

One of the main differences regarding the different health care systems, is the effectiveness of a system with regional distribution and one with national administration. Spain and Italy are such systems, that give responsibility for the execution of telemedicine to regional authorities, which leads to a lack of guidance on a national level because no uniform guidelines are given. This leads to several good or better situated regions, like Catalonia in Spain or the Lombardi in Italy, but also to a lot of badly positioned regions.

Some groups need special attention by telemedicine during this pandemic. These include elders, patients with mental health issues and patients with chronic illnesses like diabetes because they need regular medical care. Telemedicine is well suited for each of the groups in one or another way. Elders for example are not always mobile and especially in times of COVID-19 at a high risk of mortal illnesses.

These two factors and a more and more ageing population explain why European countries emphasize the need for telemedicine for elders. Therefore, the Dutch government for example made efforts for elders to monitor and transmit vital parameters digitally to their practitioner. Chronically ill patients were also included by this measure. One prominent example for the adaption of telemedicine is the care for diabetes patients. Studies in Norway and France concluded positive experiences about the use of telemedicine. Consultations with patients were held via telemedicine and their blood sugar level was monitored remotely. Expanding the findings on telemedicine for diabetes to more chronic illnesses, it can be concluded that telemedicine is very effective for these types of illnesses because there is no need for a physical examination and monitoring by doctors. These disadvantages do not apply for most chronic illnesses because patients have already been diagnosed and monitoring can mostly be done by the patients themselves (blood sugar level, blood pressure).

The last group which needs special attention are the patients with mental health issues. For this demographic, telehealth works especially well, because they do not need physical examinations. Telemedicine in this field has been adapted very well by countries or their regions. The better situated regions Catalonia in Spain and Lombardi in Italy for example offered good options like a web portal, urgency evaluations for each patient and teleconferences were the measurements of choice.

Germany presents an example for a strictly regulated system in terms of data security and privacy as well as limitations to what telemedicine is allowed to do. Several European countries must cope with these limitations when implementing telemedicine measures. Some projects in the field of telemedicine or telehealth have already been shut down over the course of the COVID-19 pandemic due to privacy concerns. Therefore, changing from the analog, well known, consultations to teleconsultations or telemedicine measures might be avoided by some practitioners.

V. Conclusion

All evaluated countries made advancements in the field of telemedicine during the COVID-19 pandemic, but each starting at a different point. Germany did not change a lot but had been starting on a high level because they advanced telemedicine over the last years. France adjusted their regulations on telemedicine but also had no need for much change. The Netherlands were at a very good point when the pandemic started and pushed it even further by loosening policies, funding telemedicine projects, and starting specialized COVID-19 telemedicine care. Norway showed itself as neutral in terms of telemedicine. Telemedicine in Norway is well known and a significant increase in patients using it have been reported, along with some changes in treatment methodology. Spain and

Italy are both facing a difficult situation due to the regional responsibilities and the resulting regional differences. Therefore, Spain's Catalonia is much better situated in the field than others. Italy in general presents an underdeveloped telemedicine situation and started from there by testing small and regional measurements and projects.

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Online communication between physicians and patients in times of the COVID-19 pandemic – systematic review of the impact on physicians' work, patients' health and well-being, and the perspective of both parties

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Abstract— **The outbreak of COVID-19 had a serious influence on the treatment of patients worldwide. Due to rapid increase in the use of telemedicine, the acceptance and influence of this online method of communication between patient and doctor has to be assessed. A research of articles was conducted in the search engine PubMed. Generally, patients and physicians were willing to use online communication for the provision of healthcare and had positive experiences. Patients had a high acceptance and satisfaction regarding the provision of healthcare through online communication with their doctor. A preference in face-to-face visits was detected in some specialties. Apart from saving time and traveling, online communication is perceived to facilitate access to healthcare for people with access to technology and can help relieving feelings of anxiety and loneliness. Even though clinicians see a high relevance and made positive experiences, some deemed online communication as an inappropriate replacement and prefer in-person visits. Still, physicians are willing to use telemedicine even after the pandemic. Physicians benefit from time and cost effectiveness of this modality. Though some difficulties, such as technical implementations and internet access are still encountered, overall, high acceptance of online communication was shown. Virtual visits are a possible alternative to traditional doctor appointments and will probably develop in the future.**

Index Terms— **COVID-19, online communication, patient-doctor relationship, telehealth, telemedicine**

I. Introduction

ON March 11, 2020, the World Health Organisation (WHO) declared coronavirus disease-19, which is caused by the severe acute respiratory syndrome corona virus 2 (SARS-CoV-2), a pandemic due to the high number of new cases [1].

The novel coronavirus disease 2019 (COVID-19) pandemic represents an unprecedented global challenge that had and still has a profound impact on people's lives. Businesses, gatherings, travel, and many types of transportation have been closed to stop the spread of COVID-19. This also had an impact on the healthcare system. While the spread of SARS-CoV-2 and the extent of the emergency situation developed differently in different countries, the outbreak has drastically influenced the treatment of patients worldwide due to preventive measures and efforts to control infection.

The progression of the pandemic has raised the question of how patients with an increased risk of infection, such as the elderly, chronically ill, or immunocompromised patients (e.g. cancer or rheumatism patients) can be protected from infection and still receive much needed medical care of high quality. Precautions include contact prevention with potentially contagious people, which also means reducing physical connections between these and the healthcare workers. To protect the patients and as the result of the social distancing guidelines, other possibilities for providing healthcare were necessary. Telemedicine has emerged as an attractive alternative [2].

Telemedicine is not a new topic; it has been used for several years, the frequency of use has increased in recent years. However, the spread in some countries (e.g. USA, Japan, and Korea) was slowed down due to strict regulatory laws and a lack of supporting payment structures [3]. Telemedicine has been shown to be a promising technology that offers several advantages, including patient convenience, reducing the number of emergency rooms, improving continuity, reducing costs, protecting healthcare resources, saving travel time and costs as well as reducing patient waiting times in hospital. However, telemedicine can have some drawbacks that should not be ignored. These include the lack of available technological resources, data security issues, increased doctor burnout due to screen fatigue, potential loss of information due to the limitations of the medium, difficulties in discussing sensitive issues, and effects on the patient-doctor relationship regarding empathy and compassion [4] [3].

Due to the overwhelming benefits, the use of telemedicine offers promising potential to reduce the spread of COVID-19. The patients can be treated remotely, thus the physical distance can be guaranteed for the safety of the patients and the physicians [4]. This has also led to a major change in the perspective on telemedicine. A few months ago, the focus was often on technical challenges and regulatory laws, yet today the focus is on opportunities emerging for patients, physicians, and even the healthcare system as a whole. The use of telemedicine increased rapidly as a result.

For the remote treatment of patients, online communication (e.g. video conferences, telephone calls, and emails)- a partial aspect of telemedicine - between physicians and patients is particularly important. This type of communication plays a vital role in avoiding crowds in hospitals and in reducing unnecessary contact with physicians.

Online communication has thus developed into a crucial instrument for providing care during social and "medical" distancing. Doctors have advocated the use of online communication in many different specialties. One example of this is the uro-oncology outpatient clinic at the Ludwig Maximilians University Hospital in Munich (LMU). Due to the COVID-19 pandemic, a total of 101 patients with advanced genitourinary cancer were treated or monitored "virtually" in the uro-oncology department. Various telemedicine services were implemented for virtual treatment in order to limit the number of potential risk situations without compromising the therapies. With the uro-oncology team, a network of oncologists, radiologists, and general practitioners has been established to oversee patient monitoring and treatment decisions. The patients are discussed in virtual multidisciplinary tumor boards via video conference in order to reduce the risk to health workers. In addition, when possible, patients are mostly managed virtually, including, for example, performing imaging scans at the radiologist's office, holding teleconferences or videoconferences to discuss test results, and regular digital symptom monitoring [5].

The transfer from face-to-face to online communication is one of the most important changes caused by the pandemic. Due to the rapid increase in the use of telemedicine, it is important to assess whether this method of communication between physicians and patients is accepted and, if so, preferred. In addition, it must be considered how this method of communication affects the work of physicians and it must be ensured that patients can be offered high-quality care with a positive influence on the health and well-being of the patients. Health is understood to mean that the patient is free from physical and mental complaints. The personal feeling of a patient is considered under well-being. In addition, the perceptions and expectations of patients and physicians must also be taken into account. These assessments can also be used to analyse whether this communication method is a sustainable solution that can be maintained beyond the pandemic and for possible other critical situations, or whether it is a solution that may only be used to deal with this pandemic.

For these reasons, a systematic review of online communication between physicians and patients in times of the COVID-19 pandemic is conducted in this paper. This examines how online communication affects the work of physicians and the health and well-being of the patients. Furthermore, the thoughts and opinions – perspectives – of physicians and patients in regard to online communication are considered.

Andrews et al. [6] already performed a systematic review on the satisfaction of patients and health care providers with the use of telehealth solutions or telemedicine during this pandemic. They report levels of satisfaction based on scores of their included studies for both examined parties and compare with inpatient satisfaction, where possible. However, the willingness to use telemedicine and its acceptance of these parties are not specifically examined, which could differ from reported satisfaction. In addition, the possible consequences of telemedicine use on affected parties are not investigated. This systematic review addresses these missing aspects. The willingness to use and the acceptance of telemedicine for patients and physicians are investigated. The satisfaction is also re-examined since new studies have been published, which provide new insights that should be considered. While focusing on direct online communication used to treat patients rather than on telemedicine in general, we investigate its impact on each party that is identified so far.

In order to achieve the goal of this paper, a literature review will be carried out to summarize the currently available knowledge on this topic. This allows the current status and a possible development to be assessed critically.

II. Methods

The steps of the research were as follows:

1) define the inclusion and exclusion criteria of articles
2) define a search strategy, create a search string
3) analyse and filter all articles that resulted from the search string based on the titles and abstracts
4) analyse and filter the remaining articles based on the full text
5) use the remaining included articles for the systematic review
6) identify further articles through cross-references, filter those and include the remaining ones in the review

A. Exclusion and inclusion criteria

The criteria are summarised in the table I.

Only the articles that are peer-reviewed were included in the results to ensure the base quality of this review. Additionally, only the articles that were written or translated in English and have an available full text were included.

As we are researching the changes that SARS-CoV-2 brought to the communication between doctor and patient, we only included the articles that were published after December 31, 2019, when the first COVID-19 case was reported.

Though, we did not only restrict to patients that have or had COVID-19, but also included those articles that reported about patients in general – cancer patients, patients with mental disorders, patients suffering from epilepsy and others. This is, because the aim of this paper is to study how general communication between doctors and patients evolved after transferring part of connections between the parties into online format. In this case limitation to COVID-19 patients would be too restrictive and would probably not give the adequate scope for the review.

Although we specifically searched for the key-word "doctor" (see II-B), we broadened this term and also included publications that report about physicians, nurses, assistants and residents (medical students, that are receiving training in a specialized medicine area) that have the same purpose of communication with patients – to diagnose and to treat them. Papers that delineate communication between patients and medical students not performing in the role of physician should be excluded, because the aim of such communication

TABLE I:
Inclusion and exclusion criteria used for the literature research

	Included	Excluded
Validity	Peer-reviewed and data driven	Not peer-reviewed or not data driven
Language	English	Any other language
Text	Full text available	No full text available (e.g. only abstract)
Time span	Published during the COVID-19 Pandemic (y. 2019-2020)	Published or based on results of studies done before the COVID-19 Pandemic (earlier than Dec 31, 2019)
Patients	All patients (not only COVID-19)	-
Hospital workforce	Doctors, Nurses, Assistants, Residents (students)	Students, that don't participate in treating patients
View	Impact on or perspective of patients/hospital workforce	Tools, Implementation, Guide/ Guidelines, Practical tips, how-to and know-how, (dis-)advantages of telemedicine
Art of communication	Direct online communication between patient and hospital workforce	Indirect online communication , face-to-face appointments or any other form of communication between other parties

is not the treatment of the patient, but mostly the learning process of the student.

We only included the articles, that outline either the impact of online communication on the work of physician or on the health and well-being of the patient or the perspective on this type of communication of one or both described parties. Articles that consist of practical tips, know-how, guidelines, and guides on how to use telemedicine and how to deploy the tools for online communication in the hospitals, clinics and outpatient care were excluded, because they do not report any impact or patient's / physician's opinion.

The final criterion is the art of communication. Any direct *online* form of communication between physician (or hospital workforce, that meets the inclusion criteria) and patient – phone calls (audio calls), video calls, messages, chats, emails – was considered as online communication and is to meet the inclusion. The communication exclusively in form of forum or social media faced the exclusion, because the users of those post their messages as a form of broadcast, not directing it to a concrete person, thus it is to be treated as indirect. Furthermore, any articles reporting on communication between any other parties, e.g. between patients and the government, or between physicians should be excluded, as these do not serve the purpose of this systematic review.

B. Search strategy

The main research was conducted in PubMed – the free search engine, that primarly accesses databases, which focus on medicine and biology related articles, yet do not restrict just to biomedicine, but include amongst others the scope of Information Technology, e.g. telemedicine [7]. Thus, it gives the right scope of articles for the question, researched in this systematic review.

The following search string was used for the literature search: ((online communication) OR (telemedicine) OR (e-Health) OR (telehealth)) AND ((patient perspective) OR (doctor impact)) AND (COVID-19). The articles resulting from this search string should report about either online communication, telemedicine, telehealth or e-Health. These definitions were treated as interchangeable in our research, as each of them describes shifting a part or the whole contact between patient and physician from face-to-face into virtual, remote form.

Moreover, the article should include the keyword "COVID-19", because we are interested in how the communication changed in terms of the global pandemic that resulted from the population getting infected with SARS-CoV-2, which triggers the COVID-19 disease.

C. The article analysis

Twenty sample articles were chosen randomly from the result pool and analysed based on the titles and abstracts to see which percent is acceptable according to the defined inclusion criteria. This was done using the four eyes principle to estimate the quality of the search string and to predict how many papers from the result pool approximately are suitable for our review.

After ensuring the satisfactory quality of the chosen search string, all the articles which we accessed through PubMed using the described search string were analysed based on the title and abstract to see if these meet all the inclusion criteria. Articles that remained included after the last step were examined by thorough studying of the full text and applying the inclusion/exclusion criteria. The remaining articles were included in this systematic review.

Further articles, suitable for our review were identified through cross-references. We used the included articles to see what other papers they were cited by. These were again checked based on the titles and abstract and the remaining pool – based on the full text. Those that met all the inclusion criteria were included in this review as well.

All the described steps were conducted under the four eyes principle to ensure the quality of the literature research.

D. Quality criteria

To assess and describe the quality of the articles included from the research, quality criteria for a high validity were elaborated and checked on the studies. These quality criteria are not used to determine inclusion or exclusion of articles resulting from the search string, but to give an overview of the quality of those studies that were included from the research.

This allows a better understanding of results and comparison of the studies since results of studies with higher quality are more significant and descriptive.

One criterion is the sample size, because a larger sample increases the robustness of obtained results and provides a broader picture. This criterion is regarded as fulfilled if at least 100 persons participated in the study, as this number marks the threshold between larger and smaller studies included in the search string. The availability of an in-person visit control-group allows a comparison to the findings of visits conducted online and therefore makes it possible to spot differences. Thus, this criterion is satisfied if at least one control-group is provided. In addition, the generalizability of results increases as studies span multiple medical institutions, multiple medical specialities, and multiple countries. These three criteria are fulfilled if the study comprises more than one institution, more than one medical domain and more than one country. Furthermore, the use of a standardized questionnaire in surveys is seen beneficial since the questions are designed specifically to investigate a certain topic e.g. the satisfaction of patients, and using standardized questionnaires makes a comparison of survey results possible. If a standardized questionnaire is used, this criterion is satisfied. The quality of a study is greater the more of these six criteria are fulfilled.

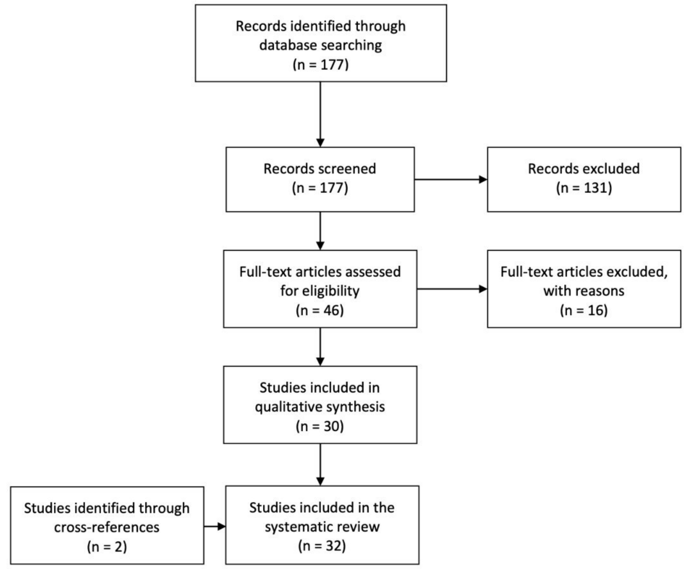

Fig. 1: PRISMA [8] Flow Diagram showing the research process of this systematic review

III. Results

The total amount of articles that resulted from the search string was 177 on the 7th November 2020.

131 were excluded after screening the title and the abstract, based on the exclusion criteria.

After thoroughly assessing the full text of remaining articles for eligibility, 16 were excluded: nine of them did not fulfill the "View" criterion, as they discussed either guidelines and practical tips for implementation of online communication, advantages and disadvantages of such, or not the impact of the communication between physician and patient was studied, but rather the impact of the pandemic on the healthcare in general. Three were excluded, based on the "Art of communication", as the online communication was not the main point of the article, but rather a minor factor. Two articles were based on research done before Dec 2019 and thus did not fulfill the "Time span" criterion. One article was not data driven and had to be excluded based on the "Validity". The detailed description of the exclusion reasons of these 16 articles are represented in the table in the appendix I.

The full process of the conducted research is presented in the flow diagram 1.

An overview of the 32 included articles is provided in the table in the appendix II.

Six of the studies were conducted in the United States. Three studies were conducted in Germany, two in the United Kingdom and six more studies covered other countries across Europe. Five publications show results from Asia, two from South America and one respectively from North America, Australia and Africa each. Three studies cover multiple countries, from which one study received results mostly from North America. Two more studies also comprised multiple countries, but the majority of respondents were from the United States.

According to the quality criteria, Garcia-Huidobro et al. [9] and Itamura et al. [10] have the highest quality, satisfying four criteria including multiple institutions, and a large sample size of at least one hundred respondents and providing in-person visit control-groups. Garcia-Huidobro et al. [9] additionally span multiple medical domains. Itamura et al. [10] use a standardized questionnaire for their study. Howren et al. [11] and Mehta et al. [12] each fulfill three criteria, which are multiple institutions, multiple countries, and a large sample size of a few hundred participants. Andrews et al. [6] conduct a review which comprises multiple institutions, multiple domains, and multiple countries. Most other included articles are surveys covering a single institution, in a single country, and in a specific domain without control-groups and some are reports and personal accounts. Thus, they are of lower quality as the already mentioned studies.

A. Patients

1) Patients' perspectives towards online communication

Out of 32 included studies, 22 evaluated the perspective of patients towards participating in direct online communication through telephone or video consultations. The perspectives compose of the willingness, the satisfaction of usage and the acceptance of online communication as the studies differentiate these three aspects.

a) Willingness to use online communication

Five of the 22 studies assess the willingness of patients to use online communication. All studies reported a high willingness of patients to use telemedical solutions in time of the COVID-19 pandemic.

In urology, 84.7% (out of 399 respondents) wish for a telemedical consultation [13]. In oncology 99% (out of 316 respondents) used telemedicine [14]. Phone calls were preferred in 92% and telemedicine in 73% (out of 385 respondents) [15]. Concerning mental disorders, Davis et al. [16] report a general high willingness to participate in telemedicine treating eating disorders.

Rodler et al. [5] report that the majority of the patients indicate a high willingness to use online communication during COVID-19. However, they report that 62.6% of patients (out of 92 respondents) in uro-oncology do not wish to maintain this form of communication beyond the pandemic.

b) Satisfaction of telemedical treatment

Eleven out of the 22 studies evaluate the patients' satisfaction of treatment through online communication. Ten studies reported a high satisfaction of treatment, while two studies report no difference between telemedical treatment and in-person treatment.

The satisfaction of patients with their telemedical appointments either with video or over telephone was consistently reported to be high and patients overall had a good experience [14, 17, 2, 18, 19, 20, 9, 21, 11, 6, 22].

Three out of the ten studies were conducted in the medical domain of oncology and cancer care [14, 2, 20]. Orazem et al. [2] report that out of 25.5% (out of 468 respondents) of patients who contacted their oncologists by phone, 92.6% had a good or exceptionally good experience. Haxhihamza et al. [18] report an overall high satisfaction in 80.22% (out of 28) of patients. Atreya et al. [20] found satisfaction in 54% (out of 50 respondents) of oncology patients.

In dentistry, Rahman et al. [17] found 97% (out of 35) of virtual clinic patients and 94% (out of 17) of patients receiving telephone consultation satisfied and their needs were met.

The high satisfaction of telemedical treatment in medical domains of chronic diseases is evaluated in two studies [22, 11]. In rheumatology, 58% (out of 429 respondents) of patients felt supported and were satisfied [11]. The satisfaction with virtual visits in rhinosinusitis care was high, but did not differ to clinic visits [22].

This result resembles the findings of Garcia-Huidobro et al. [9]. Here, the experiences of patients are rated similar to in-person care over multiple medical domains.

c) Acceptance towards online communication

Six studies assessed the patients' acceptance towards online communication. Out of those, five studies indicate a high acceptance. This reveals telemedicine to be appropriate for the situation and providing needs. Concerning the treatment of babies and children, two studies were conducted. In prenatal care, 99% (out of 283 respondents) say that their needs were met during a telemedical consultation; however a combination of means was preferred [21]. In paediatric diabetes care, Fung et al. [23] also found telemedicine to provide needs and 72% (out of 141 respondents) want future telemedical healthcare.

In urology, 62.7% (out of 766) of surveyed physicians state that more than half of their patients accepted telemedicine [24]. In rheumatology, Antony et al. [25] discovered a 98.4% (out of 550 respondents) acceptance with just 28.1% (out of those 98.4%) stating that it is only appropriate in times of strict infection control. Kerr et al. [26] found 66% (out of 66 respondents) of heart failure patients preferring telemedicine over face-to-face visits due to convenience.

In gastroenterology, 65.54% (out of 505 respondents) support an increase of telemedicine use in the future. In contrast, only in this study, 75.25% out of the 505 respondents prefers the conventional in-person treatment over the use of telemedicine [27].

Furthermore, otolaryngology patients report poor video quality and understanding of indications in video consultations [10].

2) Impact of online communication on the well-being of patients

The impact of telemedicine on the well-being of patients was assessed by 16 articles.

a) Positive impacts on well-being

Ten out of 16 articles describe positive impacts on patient well-being.

The well-being of patients was supported through some advantages of telemedicine. Smrke et al. [14] report that 42% (out of 316) of patients with rare cancers reduced their travel time and 20% (out of 316 patients) reduced travel expenses. This advantage of sparing time and money is also given by patients from radiation oncology. This was found in the study of Orazem et al. [2].

Another advantage of telemedicine impacting patients is that it is providing a sense of connectedness that made patients feel comfortable and taken care of through better access to doctors advise. This advantage has been reported by patients with eating disorders, as well as patients in oncology and psychiatry [16, 15, 28, 20]. In the study of Atreya et al. [20] 82% (out of 50) of oncology patients report that telehealth provided them with support and connectedness.

Other perceived advantages are a reduction of anxiety and loneliness in hospitalized COVID-19 patients through allowing online contact and access to information, which can relieve stress and leads to better mental health [29]. Rahman et al. [17] report patients in dentistry with dentist anxiety as being at ease and more confident in telehealth consultations, which leads to them better absorbing information. Online communication also allows maintaining a close relationship between patients and physicians in oncology; however this is limited to already followed-up patients where the relationship is already built [15, 28].

b) Negative impacts on well-being

Nine out of 16 articles describe negative impacts on patient well-being.

Negative impacts remarked in oncology include the worry of incomplete diagnosis due to missing physical examination [20] and unclarity regarding treatment plans[14]. Furthermore, there is a lack of personal contact with gestures and emotional expressions, which are needed to build a trustful relationship and convey difficult news. This effect has been reported by patients with rare cancers or heart failure, as well as it was detected in several domains e.g. radiation oncology, oncology, uro-oncology and rheumatology [14, 2, 26, 20, 5, 11]. Another major barrier to maintaining adequate health care via online communication is the lack of access to Internet, primarily concerning those below the poverty line as well as illiterate people in developing countries (e.g. in Egypt). This problem occurs in various medical domains, e.g. epilepsy, rheumatology and gastroenterology [30, 12, 31].

B. Physicians

1) Physicians' perspectives towards online communication

Perceptions of clinicians towards the use of telehealth in patient treatment were discussed by twelve articles.

a) Willing to use online communication

Six of twelve studies assess the willingness of using telemedicine.

A large proportion of physicians offer and are willing to use telehealth solutions as an alternative to personal appointments during the pandemic. In epilepsy, the willingness of physicians to use telemedicine is very high with 90% (out of 337 physicians) [30]. Mehta et al. [12] report 82% (out of 548) of rheumatologists switching to telehealth-video. Zhang et al. [27] report 65% (out of 297) of gastroenterologists using telemedicine. Telemedical measures were used by 86% (of 28 paediatric scientific societies), even if they were considered inadequate to replace physical examination [32]. In the study of Gomes et al. [24] 38.7% (out of 766) of urologists reported performing video consultations. In urology, the use was reported significantly higher ($p < 0.001$) in the outpatient sector than in hospitals [33].

b) Satisfaction of telemedical treatment

Six of twelve studies evaluate satisfaction of physicians with telemedicine and online communication. The experiences were rated positively and deemed satisfactory in psychology [34] and rheumatology [35]. Garcia-Huidobro et al. [9] and Andrews et al. [6] have reported the same results covering multiple domains, e.g. psychology, surgery. However, the study of Garcia-Huidobro et al. [9] showed that some physicians felt their clinical skills challenged regarding communication and diagnostic assessment and due to complications with this modality.

67.6% (out of 34) of clinicians deemed this form of communication satisfactory in a heart failure unit [26]. Orazem et al. [2] report 66% (out of 72) of radiation oncologists having a particularly good or good experience with patient communication using telephone consultations. Nonetheless, in rheumatology only 25% (out of 103) of physicians were comfortable providing telephone consultations to new patients compared to 87% (out of 103) of physician being comfortable providing telephone consultations to already established patients [35].

c) The perceived relevance of online communication

Five out of twelve studies assess the perceived relevance of online communication as reported by physicians. There is a strongly positive opinion on online communication and 57% (out of 28) of paediatric scientific societies consider this modality useful for chronic conditions e.g., for verbal consultation and monitoring [32]. The perceived relevance of online communication is high from 32.6 % (out of 589 respondents) of urologists [33]. Andrews et al. report willingness to maintain telehealth as part of follow-up visits even after the pandemic in multiple domains [6]. However, Zhang et al. [27] report 90% (out of 297) of physicians in gastroenterology prefer standard face-to-face outpatient clinic visits over telemedicine. Still, 72% (out of 297) of physicians think that telemedicine should replace a part of physical visits in the future [27]. Singh et al. report 50% (out of 103) rheumatologists preferring in-person follow-up. In the study of Paffenholz et al. [33], 50.1% (out of 589) of urologists state that telemedicine is only feasible for individual cases. Lubrano et al. [32] report 100% (out of 28) of paediatric scientific societies agreeing that telemedicine cannot replace in-person visits, in particular for acute patients.

2) Impact of online communication on physicians' work

The consequences of virtually conducted consultations on the physicians' work were topic in ten studies.

a) Positive impact

Three studies reported positive impact in oncology and cancer care. Smrke et al. reported positive impact on physicians work in shorter meetings without increased workload [14]. This positive aspect of decreased time burden of physician visits and also a decrease in financial burden was reported in the study of Wallis et al. [36]. Apart from less energy and time consumption, Orazem et al. [2] report less dependence and telemedical appointments as being easier to organize and more comfortable.

In psychology, Dores et al. [34] report the advantage of online communication to reach new groups of people as the access to doctor advise is easier.

The study of Albert et al. in the domain of epilepsy, showed that the increased access led to decreased no-show rates among patients and enabled participation of caregivers or family members in consultations [30]. In contrast, there were delays in appointments and increased no-shows among patients in developing countries where telemedicine was not utilized regularly prior to the pandemic [31]. This was the case for gastroenterologists in Egypt.

b) Negative impact

On a negative side, 60% (out of 589) of urologists experienced technical and regulatory restrictions that made the use of online communication difficult [33]. In epilepsy care, Albert et al. [30] also report technical difficulties and state that online communication does not provide the means necessary to conduct diagnostic monitoring or laboratory tests, which affects the physicians work negatively. Another negative impact includes an increase in workload, psychological stress, and mental effort required in consultations, which was the case in multiple domains [9].

Some negative impacts concern especially relationship-focused professions such as psychiatry and (palliative) cancer care. Those were reported by five studies, of which three are from the domain of psychiatry [34, 37, 28] and two from oncology [36, 5]. Dores et al. [34] and Wallis et al. [36] report that non-verbal cues are missing. The lack of non-verbal cues was also found in the study of Sasangohar et al. [37]. This results in more time consumption when building trust [37] and difficulties to establish relationships [34]. Pacchiarotti et al. [28] discovered similar disadvantages, reporting that psychopathological information might be lost through online communication which hampers consultations, especially with new patients. Rodler et al. [5] highlight that empathy and trust are critical in cancer care, yet telemedical consultations cannot provide transmission of signs of emotional expression such as hugs and handshakes. Similar findings are reported by Wallis et al. [36], stating that telemedicine is an inadequate modality for conveying sensitive information.

IV. Discussion

Due to the increasing number of COVID-19 cases, the implementation of telemedicine in healthcare is growing rapidly [3]. The most important tool for providing medical care while maintaining physical distance between doctor and patient is online communication. This systematic review evaluates how online communication affects patients' health, well-being and doctors' work and analyses the perspectives of both parties on online communication.

A. Summary statement setting out the main finding

The patients' overall attitude towards online communication in times of the pandemic is positive and their acceptance is high [24, 25, 26, 23] since they report a similar consultation experience compared to in-person care [22, 9]. Having better access to physicians advice, they feel relieved and less lonely, especially when being anxious about the pandemic [16, 15, 28, 20, 29]. As a result of the improved mental health and well-being of the patients, the physical symptoms of their condition (e.g. rheumatic symptoms) may be reduced. Nevertheless, personal contact and empathy of physicians in subspecialties such as oncology give patients the feeling of being understood and safe. In addition, personal contact would be more suited to deliver difficult news. Due to a lack of the personal component through online communication, these patients prefer conventional face-to-face visits [2, 20, 5]. Furthermore, the findings show that poverty is limiting the access to healthcare during the pandemic for patients, especially in developing countries. They cannot afford appropriate technical equipment, and/or do not have internet access to attend online visits, or are illiterate and not able to understand the doctor's advise correctly [30, 12, 31]. Consequently, affected patients are not satisfied with the current increase of online communication and might feel disadvantaged or even forgotten in the provision of medical care.

After transitioning to online communication, patients do not have to travel to the doctor. Hence, time management becomes facilitated for both, doctor and patient. Simultaneously, new groups of patients, for example patients who are temporarily inflexible or live in rural areas, can be reached easily [34, 2]. Such benefits explain the physicians' good experiences using online communication and, similar to patients, a high willingness to using this modality during the current pandemic [24, 27, 12, 30]. Physicians reported shorter meetings with each patient as a positive impact, especially in terms of time and financial management [14, 2, 36]. However, it remains questionable whether this might rather lower the quality of medical care and thus constitute a disadvantage.

Despite the positive effects, physicians are not entirely pleased with online communications and also report negative impacts. Physicians felt less comfortable using online communication, especially with new patients [35], as the trustful relationship is yet to be built. Towards both, new and old patients, the loss of non-verbal communication is challenging the maintenance of the patient-physician relationship, which is crucial for building trust [28, 9]. Especially in relationship-focused medical fields, such as oncology or psychiatry, humanity and personal contact are an essential aspect in medical care that help coping with the disease [37, 5]. Due to the cooperation of the physicians, they feel taken care of and not left alone with their condition [5]. Besides, in some medical fields, e.g. paediatrics or epilepsy, laboratory tests or physical examinations are a necessity [32, 30]. As a consequence, some doctors cannot perform telemedicine and therefore cannot limit themselves to online communication. Moreover, many physicians are not able to cope with the rapid digitalization of their work. Resulting technical restrictions further increase the workload and leave the physicians feeling their skills challenged and with a reduced satisfaction regarding communication [33, 9].

These findings do not seem unexpected, as the findings presented by Andrews et al. [7] already show a high satisfaction by patients and physicians regarding telemedicine. While the mentioned paper focuses on the satisfaction of patients and physicians on telemedicine in general, this review specifically examines both the perspective and the impact of online communication on physicians' work and patients' health and well-being.

B. Limitations of studies included and of the review process

This systematic review identifies some limitations of the included studies, evaluated according to the quality criteria.

Most included findings contain experience reports on the implementation of telehealth systems or perspectives obtained from questionnaires, surveys, or interviews. As a result, it is difficult to establish a general statement about the perspectives and influences of online communication. Since most studies omit a control group, the difference between in-person and virtual visits cannot be evaluated. Besides, most studies were conducted within a medical subspecialty. Hence, it is difficult to generalize the findings on perceptions in all medical areas and the whole healthcare system. Moreover, some of the studies were conducted at a single institution, so the possibility of selection bias is considerably high. They are therefore not necessarily representative of their medical specialty. The studies are not only limited to a special medical area, but also to a geographical area. Some of the considered countries are developing countries and never had any experiences with medical online communication prior to the pandemic, whereas the majority of the studies examine developed countries that have already implemented telemedicine in their healthcare system and thus are familiar with it. The differences in finances, capacities, and experiences allows neither a straightforward analysis of the effects of online communication, nor the generalization of the findings.

Based on the limitations mentioned above, the majority of the included studies are found not to fulfill the defined quality criteria and thus imply low quality. Publishing a study according to the quality criteria usually takes a long period of time. Since the first case of COVID-19 occurred barely over a year ago, there was not enough time for studies to investigate the effects of online communication on the patients' health, as it takes time for health outcomes to develop and get evaluated. Thus, it was not possible to publish many studies with high quality yet. Further publications addressing this topic and of high quality are expected next year, allowing a better assessment of the effects of online communication, especially on the patient's health.

Like in other systematic reviews, the methodology also has some limitations. Our conducted literature research is limited to PubMed. In a sample literature research of further databases, the results were not quite satisfying, as they often addressed telemedicine in general and therefore were too broad. Consequently, they did not meet our inclusion criteria. Additionally, since our research question is not a specific hypothesis, but rather an open topic, the results of the literature research on PubMed are sufficient. Furthermore, we did not use MeshTerms in the search string. There are MeshTerms that correlate with the topic, but none that mirror the intended research question to the desired degree. Accordingly, none of the MeshTerms can substitute either the search string or parts of its contents. When including MeshTerms such as "telemedicine", "patient satisfaction" or "physician-patient relations" in the search string, the results were too extensive and did not address the specific topic “online communication”, but rather telemedicine in general. Therefore, we have excluded the MeshTerms from the search string.

C. Outlook

Since the duration of the pandemic is still unclear and at least parts of the healthcare systems should be permanently equipped with online communication, special attention should be paid to patients below the poverty line. Above all, the lack of hardware and a good Internet connection should be overcome. Furthermore, patients should be introduced to the use of telemedicine. Similarly, efforts should be made to find a solution for illiterate patients. An alternative to textual contact is telephone calls, which some patients use in the included studies. Visual contact online, however, contributes to the patient's well-being relieving anxiety and loneliness. Moreover, a visual description of the symptoms of some diseases may be required [30].

Patients are generally positive about switching to online communication in times of the pandemic and report similar experiences in the quality of consultations as in-person care [22, 9]. Thus, the patients' well-being in receiving healthcare is not always directly affected by the type of communication but may depend on the experiences and communication capacities of the physician. Accordingly, more thought must be given to the way of speaking, as the resulting well-being can be perceived as good as the well-being in face-to-face visits. Considering the novelty of the pandemic, there are extremely few studies with control groups to assess the impact of online communication on patient's health. To properly evaluate the research question, we strongly suggest conducting several studies in different settings after a longer period of time within the pandemic or even after the pandemic.

V. Conclusion

This systematic review shows high acceptance and impact of online communication towards patients and physicians. It shows that virtual visits and online communication are an acceptable alternative to face-to-face visits during the pandemic as they fulfill the provisioning of healthcare services in times of social distancing.

Nevertheless, there still are some settings in which both - patients and physicians - are not fully satisfied, especially within relationship-oriented medical areas. As the rapid increase of use of telemedicine happened so suddenly, technical restrictions add to the hurdles.

With cases of COVID-19 still increasing, the virus is continuing to impact daily life. It is anticipated for online communication to remain an important part of our healthcare system even after the pandemic and therefore further development and adaption are needed.

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Appendix I
Overview of excluded publication

TABLE
Articles (n=16) that were excluded after assessing the full text of articles for eligibility and the exclusion criteria

Article		Exclusion	
Nr.	**Author**	**Criterion**	**Notes**
1.	Sullivan et al.[38]	View	Practical implementation of telemedicine
2.	Shah et al.[39]	View	Possibilities of implementing telemedicine
3.	Nowak, et al.[40]	View	Possible advantages of telemedicine
4.	Lew et al.[41]	View	Guidelines and practical tips, advantages and disadvantages of telemedicine
5.	Cervino et.al[42]	Art of communication	Only telephone call before an in-person visit, second triage in person at the appointment
6.	Weissman et al.[43]	Time span	Main findings come from the rieview, that was published before Dec 2019
7.	Vazquez et al.[44]	View	Practical tips: what needs to be done to overcome the access gap?
8.	Indini et al.[45]	View	No impact of communication change; discussion of the COVID-19 impact in general
9.	Gachabayov et al.[46]	Art of communication	Online communication is not a main point
10.	Guarino et al.[47]	View	Practical tips
11.	Baumgart et al.[48]	View	Advantages of telemedicine, not the impact or perspective
12.	Zhang et al.[49]	View	Communication is not the main point, identifies patient populations that may benefit most from virtual care
13.	Salisbury et al. [50]	View	Advantages of private video consultations
14.	Salehi et al. [51]	Validity	The article is not data driven
15.	Cacciamani et al.[52]	Time span	The survey was conducted before Dec 2019
16.	Stull et al.[53]	Art of communication	Online communication is not a main point

Appendix II
Overview of included publications

TABLE
Overview of articles (n=32) that were included in this systematic review

Author	Country	Domain	Method	Assessed modality	Institution
Albert et al. [30]	USA	Epilepsy	Online survey (n=337 healthcare providers)	Not specified / "telehealth"	Multiple worldwide (AES members)
Andrews et al. [6]	Multiple countries (53% of included articles from USA)	Multiple domains	*Integrative review*	Platforms varied among studies	Multiple worldwide
Antony et al. [25]	Australia	Rheumatology	Online survey (n=550 patients)	Not specified / "telehealth"	Single center
Atreya et al. [20]	India	Oncology	Exploratory survey; semi-structured interview via telephone (n=50 patients)	Not specified / "teleconsultations"	Single tertiary cancer care hospital
Boehm et al. [13]	Germany	Urology	Prospective phone interview (n= 399 patients)	Videoconferencing	Single tertiary care center
Davis et al. [16]	Singapore	Eating disorders	*Institution's experience of telemedicine implemetation*	Texting, e-mails, telephone calls	Single tertiary paediatric hospital
Dores et al. [34]	Portugal	Psychology	Online survey (n=108 psychologists)	Videoconferencing, telephone calls, e-mails, social networks, applications, chats	Multiple (members of Portuguese Psychologists Association)
El Kassas et al. [31]	Egypt	Gastro- enterology	*Report of challenges and impacts*	E-mails, video calls	No specific
Fung et al. [23]	Canada	paediatric diabetes care	Online survey including cross-sectional telehealth usability and feedback questionnaire (n=47 patients receiving telephone visits, n = 40 patients with virtual visits)	Telephone or videoconsultation using Skype Business or Zoom	Single tertiary diabetes center/children's hospital
Garcia-Huidobro et al. [9]	Chile	Multiple domains	convergent parallel mixed methods evaluation In-patient survey using Net Promoter Score (n=1187 in-person control-group) Online survey (n=3962 patients receiving telemedical care) Retrospective in-person visit control-group n=1848; Physicians: n=263)	Videoconferencing via Zoom	Multiple (two hospitals and six secondary care clinics throughout Santiago
Gomes et al. [24]	Brazil	Urology	Online survey (n=766 urologists)	Videoconferencing	Multiple (members of Brazilian Society of Urology)
Haxhi-hamza et al. [18]	North Macedonia	Psychiatry	Client satisfaction survey conducted in hospital; modified PSQ-18 (n=28 patients)	Not specified / "telemedicine"	Single university clinic of psychiatry
Holcomb et al. [21]	USA	Prenatal	Cross-sectional survey (n=283 patients)	Audio-only virtual visit	Single clinic
Howren et al. [11]	Multiple (majority of responders from North America)	Rheumatology	Online survey (n=429 patients)	Telephone and videoconferencing	Multiple worldwide
Itamura et al. [10]	USA	Otola- ryngology	Survey with standardized GC CAHPS (n=195 patients for virtual visits, n= 4013 patients for in person visits)	Videoconferencing through Doximity Dialer or Facetime	Multiple outpatient clinics
Kerr et al. [26]	Ireland	Heart failure	prospective observational report (n=278 patients)	Structured telephonic assessment	Single outpatient heart failure unit (DMP)
Lubrano et al. [32]	Italy	paediatrics	Questionnaire (28 italian paediatric scientific societies)	Not specified/ "some form of telemedicine"	28 scientific societies

TABLE
Overview of articles (n=32) that were included in this systematic review

Author	Country	Domain	Method	Assessed modality	Institution
Mehta et al. [12]	Worldwide (64 countries, 50% responders from USA)	Rheumatology	Online cross-sectional survey (n=548 rheumatologists)	Videoconferencing	Multiple worldwide
Morisada et al. [22]	USA	Rhinosinutitis care	Retrospective cohort study: survey with PSQ-18 (n=35 patients in-person visits, n=34 patients video consultation)	Videoconferencing	Single medical center
Odeh et al. [19]	Jordan	Type 1 Diabetes care	Online Questionnaire-based cross-sectional study (n=235; age: 1-21 years)	Telephone calls, messages, WhatsApp	Single outpatient clinic
Orazem et al. [2]	Slovenia	Radiation Oncology	Quantitative cross-sectional electronic questionnaire (n=468 patients, n=101 physicians)	Telephone or e-mail	Multiple (cancer care center and national cancer patients association)
Pacchiarotti et al. [28]	Spain	Psychiatry	*Personal account*	Telephone, chat, videoconferencing	No specific
Paffenholz et al. [33]	Germany	Urology	Online survey (n=589 urologists)	Telephone calls, videoconferencing	Multiple across Germany
Pappot et al. [29]	Multiple	COVID-19 patients	*Observational case stories*	E-health tools	No specific/multiple
Rahman et al. [17]	U.K.	Dentistry	Questionnaire study with two groups (n=35 patients virtual clinic, n=17 patients telephone consultations)	Virtual clinic (Attend Anywhere telehealth system), telephone consultation	Seven clinics
Rodler et al. [5]	Germany	Uro-oncology	Questionnaire survey mainly conducted via e-mail or telephone, some patients questioned during in-patient visits (n=92 patients)	Telephone or videoconferencing	Single outpatient unit in a tertiary care hospital
Sasangohar et al. [37]	USA	Psychiatry	*Report on implementation of telepsychiatry and applied case study*	Videoconferencing through Cisco Webex or Facetime and Microsoft Teams, e-mails, telephone, EHR, patient portal	Single outpatient psychiatric clinic
Singh et al. [35]	USA	Rheumatology	cross-sectional survey (n=103 rheumatologists/ rheumatology care providers)	Telephone, videoconferencing	Multiple (rheumatologists of Veterans Affair facilities)
Smrke et al. [14]	U.K.	Rare Cancers	Online or paper survey (n=316 patients for use of telemedicine, n= 248 patients for experience of telemedicine, n=18 clinicians)	Telephone	Single hospital unit
Tashkandi et al. [15]	Saudi Arabia	Oncology	Electronic survey (n=385 patients)	Telephone calls, electronic patient portal, mobile application, telemedicine, text messages	Single center
Wallis et al. [36]	Multiple	Genitourinary Cancer Care	*Collaborative narrative review*	Telemedicine, telemonitoring, multidisciplinary tumour boards	No specific/ multiple
Zhang et al. [27]	China	Gastro-enterology	Observational cohort study; attitudes with electronic questionnaire survey (n = 414 patients using telemedicine one month pre-outbreak, n = 409 patients using telemedicine one month post-outbreak; n=297 physicians)	Online clinics (at hospital or third-party online clinics), WeChat	Single tertiary inflammatory bowel disease center with patients from all regions in China

Treating Children With Mental Health Issues During COVID-19
A Survey of Recent Teletherapeutic Approaches

L. Buchweitz, V. Hoffmann, S. Wedel

Abstract— **Within weeks the COVID-19 pandemic changed the lives of almost everyone around the globe. The impact of the pandemic on children is of particular importance, as such exceptional situations may cause mental health problems which can lead to long-term consequences in adult age. To cope with this increased need for psychological support the field of teletherapies has been growing rapidly during early 2020. This literature review provides an overview of teletherapeutic interventions targeted to treating children's mental health problems caused by COVID-19. We summarize teletherapies from 16 relevant articles and categorize the individual components according to their underlying technologies: 1) synchronous components, to enable real-time communication over distance (e.g., telephone or videoconferencing) and 2) asynchronous components, to provide child patients with increased flexibility to engage in therapeutic activities whenever they want (e.g., apps, games or online content). We found all remote interventions to provide at least one synchronous component, and six approaches providing complementary asynchronous components. While several articles describe approaches providing synchronous components only, no article reports on a teletherapeutic approach composed of only asynchronous components. We discuss potential reasons for this imbalanced distribution and investigate implications of including components from one or the other category into teletherapeutic approaches for children.**

Index Terms— **Consumer Health Informatics, Psychological Support, Telemental Health, Videoconferencing**

I. Introduction

The COVID-19 pandemic, which originated from China in December 2019 [1], has rapidly spread around the world and led to a fundamental change in regular daily structure and unusual supply bottlenecks. National lockdowns were declared, requesting many people to work from home whenever possible, keeping at least 1.5 m distance to others, schools and shops were closed and social contact should be reduced to a minimum. This challenged especially children's mental health, as their whole life changed within weeks. The impact of COVID-19 on a child's development harbors the danger of long-term consequences of gaps in education, social misconducts or serious mental health issues in adult age [2]. Moreover, the reduction of social contacts to a minimum and shift of staff resources to treating COVID-19 patients led to the immediate suspension of about 50% of face-to-face therapy sessions [3]. Therefore, implementing suitable mental health therapies for children as fast as possible was of vital importance [4]–[6]. With modern technologies, promising solutions in therapeutic services are easily available, for example using telephone, video conferencing tools, apps or internet-delivered programs [3]. These virtual therapeutic services are called teletherapies and there is evidence that these interventions can be equally effective to their traditional face-to-face counterparts [2], [7]–[11].

Teletherapies are therapeutic interventions supported by technological components which enable the provision of the service over distance [12]. The technological components of teletherapies can be categorized based on their underlying technological characteristics. Technologies which support real-time therapy sessions, e.g., telephone or video conferencing, are categorized as synchronous components, as their main goal is to provide services over distance (spatial independence) [9], [13]. In contrast, asynchronous components are technologies that allow people to engage in therapeutic activities whenever they want, representing temporal independence.

In this work, we analyze the current state of the art for teletherapies treating specifically children's mental health problems, which are linked to the pandemic situation. Based on a systematic literature review, we provide a detailed overview over suggested teletherapeutic concepts and remote interventions which have already been implemented in daily clinical routines. We analyze the described teletherapies regarding synchronous and asynchronous components and discuss potential reasons why these might have been implemented, as well as benefits and challenges of each component.

II. Medical background: Impact of COVID-19 on children's mental health

In this section, we discuss how pre-existing mental illnesses might worsen due to increased stress levels, caused by the pandemic and how new mental health problems might emerge.

Children are particularly vulnerable to serious mental health consequences [14]. Shah et al. report that the globally leading cause for disabilities in children and adolescents are mental health problems [15]. About 15% of all children and adolescents have mental health problems or conditions. If not treated, a child‘s mental development can be drastically and detrimentally impacted which can have negative impacts, even in adult age [15], [16].

We differentiate two different effects of COVID-19 on children’s mental health: 1) some children have pre-existing mental health problems and need continuity of treatment or even more intensive treatment due to a worsening of their condition, 2) others experienced new mental problems as a direct reaction to the pandemic situation.

A. Impact on Pre-Existing Conditions

Many children with pre-existing mental disorders experienced a worsening of their condition during COVID-19. For example, 35% of 533 children diagnosed with ADHD experienced a decrease in well-being, according to their parents [5]. Due to a disrupted daily structure, healthy sleeping patterns may deteriorate, reducing psychological well-being on the one hand, but also bearing the risk for drug therapies to be less effective on the other hand (e.g., children with ADHD) [5], [17].

Eating disorders are often associated with health anxieties and contamination fears, which can cause symptoms of eating disorders to worsen as well [3]. Unfortunately, increased mental stress levels caused by the pandemic situation, can even bear the risk for healthy children to develop eating disorders [3].

Moreover, increased psychological strain can specifically challenge the development and progress of children with developmental disorders. For example, children with autism spectrum disorders (ASD) have great difficulties with communication and social interaction, especially in early childhood [18]. Due to these challenges they often suffer from anxieties to communicate with others a later age [19].

B. COVID-19 Specific Impact

Children were exposed to several significant changes at the same time which can easily add up in an increased stress response during the pandemic situation [5].

For example, the closure of schools and day care centers can lead to significant difficulties in emotional regulation at home [2]. The lack of social contact with other children can disrupt interpersonal relationships, which may affect the development of social skills [14]. The immediate suspension of recreational activities can easily cause frustration and boredom, increasing the potential for emotional arguments within the family [4]. For families living in a flat or a small house the need for private spaces increased, leading to unusual interpersonal challenges [10]. Moreover, the fact that many parents were working from home increased the tension between children and their parents rooting in either a lack of support and supervision due to extended working hours or an increased supervision and control due to being at home all day [3]. Sometimes, parents might even project their own stress on their children (e.g., financial stress due to job loss, or emotional stress due to the loss of a loved one) [5], [8]. In extreme cases, negative coping behaviors of parents can even lead to child maltreatment and violence, impacting children's physical but also mental health significantly [14].

Finally, wrong or insufficient information about the virus can elevate fears, anxieties and stress towards the pandemic itself [5]. Especially older children who can grasp the extent of the situation may suffer from increased anxiety [5]. This development is very much influenced by the parents and the family of a child [6].

III. METHODS

The collection and selection of relevant resources was conducted in a systematic search in three popular scientific databases: PubMed, Google Scholar and Web of Science. For all three databases the same search strategy was applied. A preliminary, informal search revealed the usage of different wordings among similar teletherapeutic approaches. Therefore, two search strings were applied to reduce wording bias and incorporate as many approaches as possible.

The systematic search was conducted in October 2020 using the following two search terms:

1. \`teletherapy´ AND \`mental health´ AND \`child´ AND \`COVID-19´
2. \`telemental health´ AND \`child´ AND \`COVID-19´

From all results obtained, we have preselected all English, peer-reviewed articles, published in 2020 for more detailed investigation. Content-wise, an article was accepted as relevant, if it described at least one teletherapeutic approach targeted to treating COVID-19-related mental health problems in children. To standardize the selection process, we have adapted the following definitions:

A. Children

Whereas the UN Convention on the Rights of the Child defines children as people, who have not yet reached the age of 18 [20], we chose a more fine-granular approach, separating children from adolescents. Therefore, we adopted the classification of Marques de Miranda et al. [21] who define the age range for children between six and 15 years. However, we have expanded this definition to an age range between three and 15 years, in order to also include approaches targeted to younger children.

B. Teletherapy and Telehealth

As described in the introduction, we have adopted the definition of teletherapy by Solomon and Soares as the “use of electronic information and telecommunication technologies to support long-distance clinical health care, patient and professional health-related education, public health and health administration” [9].

IV. RESULTS

The systematic search obtained different numbers of results for each search string in each database. GoogleScholar provided the largest number of results compared to the alternative databases. More precisely, for “teletherapy AND "mental health" AND child AND COVID-19“ GoogleScholar revealed 178 results, PubMed 2 and Web of Science did get one hit. The search string “"telemental health" AND child AND COVID-

19" yielded a comparable result. GoogleScholar dominated with 278 results, PubMed provided 7 hits and Web of Science found five. After filtering all results for the above-mentioned inclusion criteria, 24 relevant articles were selected for full text analysis. After deleting duplicates, 16 final articles remained, which were included in the review. From the resources cited in the found articles, four papers have been used to inform our descriptions. However, these resources were only used to provide more detailed information on already described approaches and are therefore not treated as part of our article selection.

According to the result of the systematic review, pre-existing mental conditions which worsened due to the increased stress induced on children and families by COVID-19, include eating disorders [3], [10], [22], ADHD [17], autism spectrum disorder [9], psychiatric disorders [16] and developmental disorders [8]. The lack of daily structure [3], [17], increased stress due to food-insecurities, separation from peers and boredom [10], [22] and increased health anxiety, as a symptom of the disorder [3], [22], were among the most common reasons for the respective mental condition to deteriorate.

Similar to the findings reported in section II, some articles report on generally increased anxiety, challenges in emotional regulation, as well as potential trauma resulting from experienced maltreatment and/or violence [2], [4]–[7], [13], [14], [23].

In the following sections, we will describe the different teletherapy approaches regarding their underlying technological structure, the therapeutic methods, as well as results obtained from testing the teletherapy approaches in the field, if available. Both sections are divided into several subsections, grouping the approaches into different therapeutic standards described in the articles.

A. *Synchronous Components of Teletherapeutic Approaches*

The most prominent technologies that provide synchronous, i.e., real-time interactions between health care provider and patient, are telephones and video conferencing tools [2], [9], [16]. Out of the 16 relevant articles, all articles report on having used or at least having considered to use synchronous components in teletherapy interventions.

1) *Initiation of New Therapeutic Steps*

Solomon and Soares [9] are summarizing the results of several approaches which assessed symptoms specific for Autism Spectrum Disorders (ASD) and their severity in children via teletherapy. These assessments can be vital for defining a suitable therapy framework or evaluating if a defined framework is still suitable. The authors report that digital assessments using video conferences were found to be equally usable and reliable as traditional instruments [9]. Additionally, symptom assessment and categorization of ASD might be particularly well-suited for video conference sessions, as it primarily relies on conversation. However, the authors see challenges in assessing children with more subtle symptoms, which is common in ASD, as the disorder can manifest in many ways [9].

These positive results of remote symptom assessment in ASD cannot be necessarily generalized to other mental health conditions. For example, the article by McGrath [17] describes a teletherapy approach aiming at child patients' treatment of ADHD. The evidence-based service provides early access to assessment and treatment for children with ADHD. The author reports on delaying the beginning of medication therapy in several cases, as important examinations were missing, and children and their families declined joining remote physical assessment. The main reasons for this were either because the families reported on not feeling adequately informed or not having the necessary equipment at home (e.g. for blood-pressure measurements) [17]. More positive results were yielded among children who received optimized medication treatment, as they were able to continue their treatment remotely using video conferencing tools and telephone without major challenges [17].

Although communication plays a major role in initiating new therapeutic steps, doing so remotely seems to be more challenging than in-person as it causes great insecurities on both sides, therapist and patients.

2) *Continuity of Treatment*

Children who receive treatment for a pre-existing mental condition rely on it to continue, also if in-person appointments are not possible (and not recommendable) during the pandemic situation. On the one hand, it is vital to keep health care quality on the same level as before the pandemic [17], on the other hand, additional efforts might be needed, to prevent the condition from worsening [3]. This holds for regular psychological treatment sessions [3], as well as for medication treatments [17].

Davis et al. report on the continuation strategy of treating eating disorders in children [3]. By implementing regular telephone consultations therapists tried to support young patients and their families in coping with the new situation and engaging them into adhering to the therapy, such as regular weighing and self-monitoring. The authors report on the potential of treating carefully selected cases with teletherapy, if patients meet specific criteria, such as willing to use new technologies, the parents' willingness to support their children and, most prominently, the medical stability of the child's condition. The authors do not go into detail about specific examples of teletherapy approaches which could be used, however they reference articles which report on promising teletherapy approaches for treating eating disorders using video conferencing tools [24], [25]. The article does not report on any qualitative or quantitative results or case studies.

Poon et al. [6] reports the implementation of a telepsychiatric service for children with psychosis in a single case study. The psychiatric and counselling sessions were transferred into the digital domain by using a video conferencing tool [6]. Preliminary results from two remote sessions were promising, as the mental state assessment of the child patient was successful, and the therapist agreed with the patient and the family on an ongoing medication plan [6]. One prominent advantage that particularly helped the professional in continuing the therapy was the absence of facial covering, which facilitated the assessment of facial expressions [6].

Children with neurodevelopmental disorders, as well as their families are particularly affected by the lack of daily structure and the absence of daily rehabilitation and recreation activities [8]. In a Child and Neurology and Psychiatry Unit a remote video conferencing service was launched providing immediate mental support to reduce emotional distress and psychological burnout in children, as well as emotional and psychological support for the parents [8]. Provenzi et al. report on having enrolled more than 80 families with a participation rate of almost 100% at the time of article submission [8]. Preliminary results yielded that the parent's main concern was the continuity of their child's rehabilitation program, since the situation had remarkable effects on the children´s well-being [8].

3) Cognitive Behavioral Therapy

Cognitive Behavioral Theory (CBT) is one of the most recommended psychological therapies for the treatment of eating disorders [26]. There is evidence where CBT conducted via video conferencing tools yielded good clinical effects in children [9], [10], [13].

The core components of CBT are self-monitoring activities of nutritional intake, feelings and thoughts that help the patient in getting a better understanding of their own situation, and foster adoption of a healthier diet [26].

Graell et al. conducted an eight-week study during the COVID-19 lockdown in early 2020, combining teletherapy with outpatient or day-hospital services for children and adolescents with eating disorders [10]. They implemented telephone consultations and therapy sessions using video conferencing. From all children evaluated (n = 13, school-age), 69.2% had remote sessions only and 30.7% received a combined therapy with occasional face-to-face visits [10]. Compared to the group of adolescents, children reported improvements in family relationships and had more stable conditions, which is why they were better suited for teletherapy sessions than more severe clinical cases [10].

Another work reports on the transmission of in-person Group Cognitive Behavioral Therapy (G-CBT) for children with a range of neurodevelopmental and anxiety disorders to teletherapy sessions [2]. MacEvilly and Brosnan describe that due to confidentiality requirements and distractibility by the technology, individual parent-child sessions instead of group therapy sessions were implemented using video conferencing [2]. Usually, teachers are also included in the group program, which was not possible for remote therapy, due to lockdown and school closure. However, conducting the therapy sessions in the patients' home environments offered the opportunity to include siblings, instead. The therapy was complemented by an accompanying online game, training the children's ability for emotional regulation and social communication [2] (see section IV B.2 *Cognitive Behavioral Therapy*). Eighteen children between eight and twelve years and their families participated in the remote CBT intervention [2]. The major anticipated challenges were difficulties in recognizing subtle changes in the patient's emotions for clinicians, the burden of acting as a co-therapist for parents and the absence of group-related activities, such as team games and informal chats for children. As the intervention was still ongoing at the time of article submission, the authors do not report on preliminary results, but expect the intervention to be equally effective as the traditional G-CBT and an increased co-production between the therapist and the patients and their families [2].

The article of Racine et al. provides a meta-analysis of different therapeutic approaches that provide benefits and challenges to the remote treatment of child trauma [7]. One of the described approaches is Trauma-Focused Cognitive Behavior Therapy (TF-CBT), which is an evidence-based, gold standard in treating post-traumatic stress symptoms in children and adolescents [7]. The authors describe several limitations of CBT-based teletherapy for trauma treatment in children, such as challenges conducting therapy sessions in a private and safe space, technological literacy and access to internet and technological devices of the child and its family, as well as problems with keeping up the child's attention during therapy sessions. Nevertheless, Racine et al. highlight that teletherapy for trauma treatment in children can be very beneficial, if it is carefully considered who will use teletherapeutic services when and under which circumstances [7].

Stewart et al. conducted a field study, evaluating the feasibility and effectiveness of remote TF-CBT with 70 children between seven and eighteen years of age [23]. The traditional procedure of TF-CBT consists of weekly sessions taking into account various aspects of trauma-related symptoms, such as psycho education, relaxation, affective modulation and cognitive processing skills, as well as trauma narration, in-vivo mastery of trauma reminders and conjoint child-parent sessions, among others [23]. The authors implemented the remote therapy using a video conferencing tool with screen sharing function. They used several approaches to foster interaction between therapist and patient. Some therapeutic methods were adapted from traditional TF-CBT, such as digital PDF worksheets, which were shared on the therapist's screen and filled out together or reminder text messages for joint sessions with the parents [4], [23]. However, the authors also report on methods that have been developed specifically for the remote therapy, for example PowerPoint presentations featuring digital games to reinforce emotion vocabulary, Jeopardy-styled psycho education games or the opportunity to jointly create a picture-based trauma narrative. The results of the field study were highly positive, with 88.6% of all patients completing the full course. 96.8% of all completers dropped from diagnosed or above-threshold scores for clinical, trauma-related disorders in the beginning, to diagnosis-free or below-threshold scores after completing the intervention [23]. However, the authors highlight that only less severe cases were accepted for the teletherapy approach, among other inclusion/exclusion criteria.

4) Parent-Child Interaction Therapy

Other therapeutic approaches report preliminary evidence that remote Parent-Child Interaction Therapy (PCIT) is beneficial for trauma treatment of children [7], [14]. PCIT is a short-term, evidence-based intervention particularly suitable to support families with children between two and seven years of age with behavioral or emotional difficulties [14]. The focus of the intervention lies on building a positive relationship between parents and their children. During therapy sessions, parents get advice from the therapist via earpieces through which parents should learn how to manage the child's difficulties and foster family communication [14]. The natural separation of the therapist from the patient and the family makes PCIT a well-positioned opportunity for a remote intervention [14].

In the context of the pandemic situation, Gurwitch et al. report about the potential benefits of online PCIT and underline this hypothesis with a recent study which tested an online PCIT intervention in a controlled trial [14], [27]. Forty children between three and five years and their families have participated in the study (half of which belonged to a control group receiving traditional PCIT). Results revealed that the online intervention showed effect in 70% of the cases immediately after the study and in 55% after six months. In the control group, 55% of the patients showed effects at the end of the study and 40% in the follow-up evaluation [27].

A similar approach is reported by Wade et al. [11], called Online Parenting Skill Intervention. Although originally targeted to children with traumatic brain injury, the authors suggest that this therapeutic method might also help children and their families in coping with the increased stress caused by COVID-19 [11]. The intervention consists of two modules: a self-guided learning phase for the family and subsequent therapy sessions in which the parents are guided while playing with their child to practice the content from the learning phase [11]. The authors report on several trials which have been conducted using this methodology, with good results regarding efficacy, usability and acceptability [11].

5) *Family-Based Therapy*

Matheson et al. describe considerations of translating traditional family-based therapy (FBT) into the digital domain using video conference tools [22]. FBT is a therapeutic approach that empirically supports effective treatment, for example for children and adolescents eating disorders [22]. However, to date, there is only little research on the efficacy of remote FBT for treating children with mental health problems [22].

Matheson et al. report on clinical experiences with providing FBT as teletherapy, by highlighting several challenges that need to be carefully considered, when transferring traditional FBT into the digital world. For example, younger children might struggle to keep focused and communication strategies, such as everyone sitting in a circle to foster interpersonal communication, is limited through the technological setup, e.g., view angle of the camera [22]. However, remote FBT can hold benefits that traditional FBT cannot provide, such as practicing new interpersonal behavior patterns in a familiar environment. The therapist can get additional insights into the home environment of the children, which can help with finding causes of the children's eating disorder. However, the article does not report any evaluations of the clinical experiences they have made with remote FBT [22].

6) *Mental Support*

As described previously, the confinement, food insecurities, the separation from peers and the lack of daily structure has unique effects on children which can lead to increased stress and anxiety. To prevent future mental conditions, it is important to support children's various symptoms immediately. However, due to a wide variety of psychological reactions, the support methods also need to be manifold and do not necessarily follow specific therapy protocols, but provide general mental support and advice, instead.

Endale et al. report on a broad, multi-language support service for refugee and immigrant children and families [4]. Several services using synchronous technology, i.e. video conferencing, were organized. For example, group video calls for children to meet and connect to peers of the same age and storybook reading sessions for younger children with reassuring mental health or COVID-19-related topics were established [4]. The authors describe the various components of their service, but do not report on any quantitative or qualitative evaluations.

Finally, Sharma et al. report that the Children's Hospital in Seattle transitioned 90% of all face-to-face interventions to teletherapy sessions for their patients in only 4 weeks of time [16]. After this period, also the enrollment of new patients was planned. The teletherapy sessions included individual interventions, but also group sessions [16]. The authors are focusing specifically on the implementation of such teletherapy services from a clinical perspective and thus not report on any evaluations from the view of children and their families [16].

7) *Summary of Synchronous Components*

The application of two synchronous technologies is mentioned: telephone and video conferencing tools. Notably, the distribution between these technologies is not balanced. Telephone consultations are reported in three articles as an intermediate stage between in-person and remote therapy [3], [10], [17]. In contrast, video conferencing tools were used by all articles.

Regardless of the underlying technology, the evaluation results reported are similar. Eight out of sixteen described approaches using synchronous components report on some evaluation results. Seven articles present positive results [6], [8]–[11], [16], [23] (see table 1).

Three articles describe evaluations on a qualitative level [6], [8], [11], six report on results quantifying their evaluations [8], [10], [11], [16], [23], [27].

Three articles support the rationale of their intervention with results from previous work [9], [11], [14], the remaining four do not report on any evaluation result at all [3], [4], [7], [22] or just mention their expectations [2] (see table 1).

One work report on negative results, indicating that the implementation of a teletherapy intervention was not successful [17] (see table 1). In particular, the diagnosing process and the initiation of new treatment steps (e.g., medication therapy) was

TABLE 1: SUMMARY OF ARTICLES DESCRIBING SYNCHRONOUS AND ASYNCHRONOUS TECHNOLOGICAL COMPONENTS, THE UNDERLYING THERAPEUTIC FRAMEWORKS IN WHICH THE RESPECTIVE COMPONENTS HAVE BEEN APPLIED, AS WELL AS A SUMMARY OF WHICH ARTICLES HAVE PRESENTED EVALUATION RESULTS FOR SYNCHRONOUS AND ASYNCHRONOUS COMPONENTS.

Components	**Technological Components**	**Therapeutic Framework**		**Summary of Reported Evaluation Results**
16/16 Synchronous	3/16 Telephone 16/16 Video Conferencing	2/16	Initiation of New Therapeutic Steps [9], [17]	• 8/16 evaluation results • 8/16 no evaluation results • 3/8 qualitative results • 6/8 quantitative results
		4/16	Continuity of Treatment [3], [6], [8], [17]	
		6/16	Cognitive Behavioral Therapy [2], [7], [9], [10], [13], [23]	
		2/16	Parent-Child-Interaction Therapy [11], [14]	
		1/16	Family-Based Therapy [22]	
		2/16	Mental Support [4], [16]	
6/16 Asynchronous	1/6 App 1/6 Website 1/6 Online Game	1/6	Continuity of Treatment [3]	• 3/6 no description of architecture or implementation • 3/6 positive results • 3/6 no evaluation results
		3/6	Cognitive Behavioral Therapy [2], [10], [13]	
		1/6	Parent-Child-Interaction Therapy [11]	
		1/6	Mental Support [4]	

perceived to be very challenging by two articles [16], [17]. Both approaches have even temporarily delayed these services until the technological infrastructure was improved.

All articles described in this section agree that there are several challenges in the design and successful implementation of teletherapies. However, many also acknowledge that teletherapies have the potential to bring benefits that traditional methodologies could not, such as additional insights into the home environment of a child patient and easier access to the relationship between a child and his family [2], [22], [23]. Further, a commonly highlighted aspect among the described articles is the importance of carefully considering a child's suitability for a teletherapeutic treatment [3], [7], [9], [10], [23]. The criteria mentioned most often were a clinical stable condition of the child, the willingness of the child and his family to use new technologies, as well as the parent's willingness to support their children.

Many articles have translated the traditional in-person methodologies of their therapies into the digital domain without major adaptations and report on positive feedback [6], [8]–[10], [14], [23]. Some approaches might even be more successful when being conducted remotely compared to the traditional way [14]. Naturally, there are also therapeutic methodologies which are less suited to be translated into the digital domain, such as group therapies, physical assessments and the editing of worksheets [2], [17], [23]. Nevertheless, the evaluation results reported for approaches which have implemented methodological changes were positive [2], [23].

Finally, it is noteworthy to highlight that some therapeutic methodologies already provide a decent research base regarding their clinical effectiveness for children via remote technology, i.e., CBT and PCIT [7], [9], [10], [13], [14]. For other approaches, such as FBT, more detailed research for remote therapy treatment for children is needed [22].

B. *Asynchronous Components of Teletherapeutic Approaches*

Asynchronous methods are the complementing element of synchronous methods. Technologies that can provide asynchronous therapeutic activities are online documents, videos, apps or games, among others. The core of this approach is that the patient can access the therapeutic material whenever he or she wants without requiring the therapist to be immediately available [8]. Out of all relevant articles, six report on asynchronous teletherapeutic components.

1) *Continuity of Treatment*

Davis et al. [3] report on the potential of treating carefully selected cases with teletherapy, if patients meet specific criteria. Besides some articles which investigated teletherapy approaches using video conferencing, the authors also reference one article which summarizes asynchronous methods actively used in China during COVID-19: digital surveys to assess the populations' mental health status and mental health education and communication programs using the popular national platform WeChat, providing digital, free-access versions of advisory books, 24/7 available psychological counselling services and self-help intervention systems based on CBT for depression, anxiety and insomnia [28]. Although these approaches are not necessarily based on scientific work, they add to a holistic overview of potential teletherapeutic approaches using asynchronous methods.

2) *Cognitive Behavioral Therapy*

Reay et al. provide an overview over the broad range of opportunities teletherapies may offer [13]. Besides synchronous approaches, using video conferencing or telephone, the authors particularly mention several asynchronous methods which are often implemented into remote treatment, such as homework assignments, email reminders and forums [13]. However, the authors do not mention specific examples in which these methods have been used. Further, Reay et al. suggest self-guided treatment programs which should enhance the engagement of the patients and provided clinical benefits similar to traditional therapist-guided interventions [13]. However, it is highlighted that the support of a professional makes substantial differences in self-guided treatments, regarding therapy adherence, completion and efficacy [13].

The main component of the remote CBT approach for children with neurodevelopmental and anxiety disorders, described by MacEvilly and Brosnan, is a multimedia, online game, targeted to improve children's emotional regulation and social communication skills [2]. Although already developed in 2008, summarizing the game adds to the understanding of what asynchronous methods can offer. The game is based on CBT and has a substantial international research base supporting its effectiveness [2]. The patient takes the role of a detective who is expert in decoding suspects' thoughts and feelings [29]. As the patient reaches higher levels in the game, the tasks get more complex and challenging [29].

In their paper, Graell et al. mentioned an e-health app that was created as an accompanying component of a face-to-face CBT therapy [10]. The app's efficacy was investigated in a multi centered controlled trial in 2019 (in which Graell et al. participated), comparing the experimental group of face-to-face CBT with complementing app to a control group receiving face-to-face CBT intervention only [26]. The study was conducted with 106 adolescents with eating disorders. The app was specifically developed for people with eating disorders and primarily represents monitoring features, for food intake and patients' thoughts, actions and emotions. Additionally, the app connects the patients more closely to the therapist by providing a chat function [26]. No differences between groups were detected, indicating that the intervention with the app is not inferior to the traditional. Although Graell et al. have participated in the study and the results were promising, the app was not used in the teletherapy approach presented in their article [10].

3) *Parent-Child Interaction Therapy*

In their Online Parenting Skills Intervention, Wade et al. provide asynchronous components prior to each remote therapy session [11]. The parents acquire new knowledge about the condition of their child (originally children with traumatic brain injury), warm and communicative family interactions and appropriate parenting strategies by reading through a website. In the next synchronous teletherapy session, the therapist would review the learned content and support parents in applying the strategies while playing with their child [11]. The positive effects from prior studies are described above in section IV A.*4 Parent-Child Interaction Therapy*.

4) *Mental Support*

In their broad portfolio of the online service by Endale et al. describe several components, using asynchronous methods to help refugee and immigrant children and families [4]. For younger children, for example, exercise videos were offered, as well as guided meditations or relaxations and educational activities to support children's mental well-being. Additionally, conversation guidelines were provided for parents, to facilitate critical exchange about the pandemic situation between children and their families [4].

5) *Summary of Asynchronous Components*

Although only six articles described asynchronous components in teletherapies, many technologies were mentioned: digital surveys [28], chat-based systems [28], e-books [28], self-help forums [13], [28], email [13], homework assignments [13], videos [4], guided meditations [4], education activities [4], websites [11], online games [2] and health care apps [10].

Three approaches mentioned several asynchronous components which could be used for teletherapeutic services [4], [13], [28]. However, neither the architecture, nor the implementation or the application in a therapeutic framework was described. Naturally, these approaches do not report on any evaluation results, either.
In contrast, the other three papers were focusing on one component each [2], [10], [11]. All three components were applied in a therapeutic framework and therefore described in detail and supported with highly positive evaluation results from prior works [2], [10], [11].

Notably, all therapeutic frameworks which were enriched by asynchronous components, belong to a well-researched therapeutic methodology, i.e. CBT [2], [10] and PCIT [11].

C. *Challenges of Teletherapeutic Approaches for Children*

In this section we describe the most prominent limitations, described by all 16 articles. As described in *A7) Summary*, it was highlighted several times that not all children might be suitable for receiving teletherapy interventions [3], [7], [10], [17], [23]. More specifically, authors recommend that only children with less severe and stable clinical conditions should be considered for teletherapies.

Further, several technical factors impacting the successful application of teletherapies are mentioned. The most limiting factors are the different technological resources available to families, such as stable and fast internet connection and technological devices (e.g., computer, webcam, headsets) [7], [11], [23]. Stewart et al. for example addressed these differences by providing families with iPads, if necessary, or implementing the teletherapy sessions at the child's school, ensuring a stable and fast internet connection [23]. Another factor affecting the successful implementation of a teletherapy for children is the child's or the family's technological literacy [3], [7], [23]. Especially for younger children, who have limited

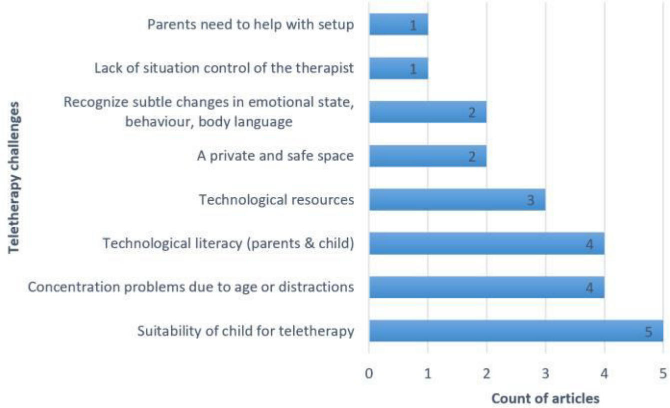

Figure 1: Overview over the most often highlighted challenges in teletherapeutic services for children with mental health problems.

experience with technological systems, need technical support to set up a therapy session. If parents are not very experienced either, sometimes therapists were required to assist with the setup [22].

Another major challenge for teletherapies is the establishment of a private and safe space similar to that during an in-person session [7], [11]. Additionally, four works report on difficulties in concentration because of age and certain distractors, such as technological components, home environment or a lack of privacy and silence [2], [10], [11], [22].

From a therapeutic point of view, major limitations in online approaches compared to their traditional counterparts were challenges recognizing subtle changes in a patient's emotional state, behavior or body language over video stream [2], [22], a lack of situation control of the therapist, for example when a child leaves the session by switching off the computer [22] and the requirement that parents are willing to help with the technological setup and therapeutic activities [13].

The article by Bate and Malberg describes a strategy to cope with the aforementioned therapeutic challenges during teletherapy sessions with children [5]. The authors suggest a mentalization-based strategy for therapists to (re-)connect to their patients over distance [5]. During situations with high emotional arousal, people usually stop mentalizing, i.e., understanding behaviors of themselves and others in terms of underlying thoughts, feelings and intentions [5]. As the pandemic situation increases emotional arousal in patients and clinicians, Bate and Malberg highlight the benefits of implementing activities to restore a mentalizing stance in both therapists and patients to foster therapeutic progress [5]. The authors report on promising results from a case study evaluation, stating that the child patient was more comfortable to communicate remotely after a mentalizing activity and reflected his own feelings in a detailed manner [5].

V. Discussion

We have found an imbalanced distribution of approaches using synchronous and asynchronous components in their teletherapy services. Whereas all presented articles report on synchronous components in their therapeutic approach, i.e. telephone or video conferencing, only six articles have included asynchronous components, such as videos, apps, games or online learning sources. There is no service featuring asynchronous components only. In early 2020, when in-person sessions have been suspended due to the pandemic situation, health care systems and therapists were under great time pressure to ensure continuation of treatment on the one hand and address the increasing need of children for mental support on the other hand. As most psychological therapies rely primarily on communication, we suppose that health care providers have translated the usually used, established, evidence-based face-to-face therapies into the digital domain, by implementing telephone consultations or video conferencing sessions as quickly as possible. Although this was vital for ensuring seamless continuity of treatment, therapists did not have time to adapt the therapeutic processes adequately to the new domain. As the technological infrastructure for video conferences needed to be established first, many approaches started remote therapy services via telephone. However, telephone consultations were only used temporarily during transition from in-person to remote services and results tend to be unsatisfactory [17]. For example, physical examinations and assessments of mimics, body language and the therapeutic setting can be very difficult. For example, therapists can easily miss important non-verbal and subtle cues because they cannot see the patient [2], [7], [9], [17], [22], [23]. Therefore, several articles report on difficulties in the beginning of the transition phase [2], [16], [17].

A. *Synchronous Therapy Components*

Synchronous therapy components provide both benefits but also challenges. One of the most striking takeaways is that there are therapeutic approaches even more suitable to be conducted remotely than in-person, such as PCIT [14]. Although it is not surprising that the natural separation of therapist and parents with their children might be specifically suited to be held remotely, the clinical standard reported in the literature seems to be still in-person [7], [14]. Taking PCIT as a highly interesting example, we suppose that the pandemic can foster an entirely new awareness among clinicians that remote therapies can also offer great benefits over their traditional counterparts instead of primarily shortcomings.

Another advantage of synchronous therapeutic approaches is that the transition of communication-based, in-person encounters to remote therapy sessions can be done rather quickly, which is key to ensure continuity in treatment [16]. Common video conferencing tools make the technical setup relatively easy to establish, and many articles state that technical issues could be resolved quickly [6], [13], [23]. Children only need limited technical support with the initial setup or might even be capable of establishing the setup themselves. After the setup, the therapy sessions can be mostly held as usual (i.e. therapeutic conversations between therapist and child patient), giving children a sense of continuity and stability during a time in which they lack their usual daily structure [3], [5], [17]. Further, therapeutic frameworks such as PCIT can be translated particularly fast, as they need minor to no adaptations in structure and process at all.

Additionally, remote encounters, using video conferencing, provide an appropriate environment for therapists to monitor regular a child's overall condition, in order to assess, if the child still qualifies for receiving teletherapy (i.e., representing a stable, not too severe clinical condition).

However, synchronous components also have some shortcomings and challenges, which need to be considered carefully. For example, subtle changes in body language, mimics or behavior might still be difficult for therapists to recognize via video stream [2]. This bears the risk of missing important indicators for changes in a child's condition, making it potentially less qualified for teletherapeutic interventions.

Moreover, if therapy sessions get more intense, the child patient can simply leave the session by switching off the computer [22]. This makes the patient inaccessible to the therapist, which is usually not the case in face-to-face encounters (even if the child leaves the room) [22]. As the therapist is not in full control of the situation (as it would be in an in-person encounter), immediate and intensive care may be missing at this point and therapeutic progress out of these situations might not be (fully) obtained. In addition, therapists do not have the opportunity to ensure the patient's well-being, which might be critical especially for children experiencing maltreatment and violence.

Another challenge with synchronous teletherapeutic components is the large number of distractors in a child's home environment. Each of them might keep the child from focusing on the therapy session, such as younger siblings [11], pets [22] or the lack of private space [10] (e.g., for children living in a flat).

A private space during therapeutic sessions is not only important for a child's attention but is specifically important for children who experienced maltreatment. A therapeutic environment in which they can feel safe and comfortable is vital for an effective intervention [7].

The approach of Bate and Malberg addresses some of these factors, by introducing mentalization-based strategies to re-establish self-reflection processes [5]. Interestingly, we have found only this article, trying to provide therapists and patients with methodological tools to cope with the new situation of remote therapy sessions. Most approaches focus recommend avoidance strategies during the design of teletherapeutic interventions, e.g. [2], [22].

Only eight out of sixteen articles report on any evaluation results, with three of them reporting on results from previous research. This distribution clearly mirrors the time pressure of the health care institutions in implementing new teletherapy interventions. Many approaches do not report on evaluation results, as interventions are still ongoing and data is still being analyzed by the time of article submission. However, at least three articles motivate their teletherapy design by highlighting positive effects from prior works. Especially under time pressure, it can be helpful to adopt designs of promising prior work and adapt it to a specific use case. This does not only facilitate a timely transition, but also supports the effectiveness and acceptability of the intervention, by avoiding known obstacles and deal with challenges during the design phase of a remote service [16]. In particular, for therapies which need major adaptations to be translatable from in-person to remote services, e.g. group therapies, it is beneficial to inform the new therapeutic design with previously acquired knowledge. This does not only help with avoiding known mistakes and increasing efficacy, but also saves time.

If therapies, not extensively investigated by prior works, need to be transitioned, there are guidelines available, which can help with the basic design [30], [31]. We hypothesize that if McGrath, for example, had considered guidelines on how to design teletherapies targeted to children, he could have improved family participation [17].

Authors from several articles highlighted the importance of regularly and carefully assessing a child's suitability for receiving teletherapeutic treatment. The primary concern is, of course, keeping the child safe and maximizing the therapeutic success. Although not explicitly stated, we argue that the most important factor for this limitation is the lacking experience and training of therapists [31]. Not all children will have clinical conditions suitable for remote therapy, however we argue that the threshold for being categorized as suitable for teletherapy will decrease in the future, once therapists are more experienced in guiding and supporting remote therapies. For example, the support of parents will be less crucial, if therapists exactly know how to safely guide a child through teletherapies and children will get used to and better educated at conducting therapy sessions via information technology. Nevertheless, it always remains very important to regularly assess a patient's clinical condition to recognize worsening and instability which might make the patient (temporarily) less suitable for receiving teletherapies.

B. *Asynchronous Therapy Components*

Similar to synchronous components in teletherapies, also asynchronous components provide several advantages and disadvantages at the same time. There is evidence that asynchronous components, such as internet-delivered components, are rated high in accessibility and convenience by patients and significantly decrease the number of missed appointments and dropouts [13]. Moreover, therapeutic content that can be accessed at any time makes teletherapies more flexible than their traditional counterparts and even monitoring activities might be more precise, as quickly noting feelings and thoughts in an app is more comfortable than doing so using paper and pen [26].

But there are some difficulties which need to be considered as well. Compared to synchronous components, regular assessments of a child's suitability for teletherapy interventions can be difficult. If therapists receive data, transmitted by the asynchronous component, (e.g. a monitoring app), they can try to infer a child's condition based on this data, however, they lack personal impressions and statements of the child, which can be key for recognizing subtle changes in condition. Moreover, therapists and parents can easily miss decreasing usage of the asynchronous component. Therefore, both parties are required to control the regular usage to a certain degree.

This, in turn, contradicts the advantage of asynchronous components being more flexible and time independent. Finally, asynchronous components require a higher technological literacy and affinity than using video conferencing tools, which might limit the application of these components to older children.

From the six articles, which reported on asynchronous components, only three reported on evaluation results yielded from prior works. This indicates that there is much less research on asynchronous teletherapeutic components than on synchronous components, which is reflected in the total number of approaches using one or the other component as well. However, the research base existing for asynchronous components is quite solid, showing that asynchronous components can add benefits to the therapy, but also need time to develop, evaluate and optimize [12], [29]. We hypothesize that the time needed to include asynchronous components into teletherapies is the major reason why only few approaches have adopted such components in 2020. For example, Graell et al. [10] report on their prior participation in a multi centered clinical trial investigating an app which supports monitoring activities in the treatment of eating disorders [27]. Interestingly, they did not use the app in the recent study, although the results from the trial were promising. One reason for this could be that it would have required more time for the authors to beneficially include the app into the remote intervention or to train therapists to appropriately support the usage of the app. The online game, described by MacEvilly and Brosnan is another example clearly showing that developing effective asynchronous components can take a long time [2]. The game was developed in 2008 and evaluated and optimized by many international researchers over the years [2]. Although, offering positive evaluations, the game does still not seem to be applied regularly in clinical routine.

In sum, asynchronous components require the patient to take an active role and personal responsibility for his or her condition. This can be both: a great opportunity, if carefully instructed and supported but a health threat, if not appropriately introduced and applied (e.g., children not suitable for teletherapy interventions). There have been some regulatory adjustments, fostering the national development of safe and effective asynchronous components for therapeutic purposes. Germany, for example, has introduced a governmental system assessing medical, mobile applications regarding efficacy, data security and interoperability [32]. If an application is officially approved by the respective institution, every German clinician can prescribe this application to a patient and the purchase of it will get reimbursed by the patient's health insurance [32]. This system clearly shows that asynchronous components are expected to provide great benefits, i.e., the government fosters their development, but also need careful regulation processes to ensure health care quality and patient safety.

To further avoid health threats and ensure the security of specifically child patients, children need to be old enough to understand the situation, parents need to be willing to support the therapy [13] and therapists need to be instructed on how to introduce and support the usage of asynchronous teletherapeutic components [31].

C. Integration of Synchronous and Asynchronous Components Into Teletherapies

As a summary, we argue that, while showing promising results, most currently applied teletherapies for children might not exploit their full potential. Whereas all approaches are using the benefits of spatial independence (which was obligatory due to suspending face-to-face sessions), temporal independence, however, is explored less often. However, most children regularly expose themselves to technology, which indicates that applying asynchronous components such as apps, games or internet-delivered programs more often, can increase curiosity and thus engagement, responsibility and therapy adherence [13]. Although the critical aspect of a child's suitability for teletherapy was highlighted primarily for approaches using synchronous components, it is even more relevant and probably needs to be expanded for approaches using asynchronous components. Children get more involved in handling their own health condition, which requires a high degree of self-responsibility and self-awareness, for example regular and critical reflection on one's own health status and sensibility to recognize when to ask for professional support. However, since asynchronous components are only rarely applied in therapeutic routines, these concerns are not yet addressed or considered extensively in the literature. We strongly recommend extending research in this area, to minimize the risk for child patients.

Nevertheless, if we assume a child has qualified for teletherapy and the therapy has reached a stable point, including asynchronous components into the intervention can complement the therapy and bring benefits [2], [10], [11]. For example, self-monitoring might be done more often and more precise and teletherapeutic services might get more cost-efficient when using asynchronous components [26].

However, it is necessary that the therapist appropriately supports the introduction and usage of the component. If this cannot be ensured, e.g., because of not enough experience or time, we suggest considering a similar approach as described by Stewart et al. to start experimenting with potential asynchronous components, while minimizing the risk for serious health threats [23]. The authors provided several interactive activities and games for child patients, using screen sharing (e.g., click-games and picture-based trauma narratives using PowerPoint, and worksheets using Adobe). Although it might seem cumbersome at first only the therapist can edit the files, this eliminates numerous of potential distractors and challenges the child to provide clear instructions to the therapist.

Interestingly, only well-researched teletherapeutic frameworks describe asynchronous components as a part of the therapy, e.g., CBT and PCIT. In contrast, therapeutic approaches with only little research about the efficacy when conducted remotely (e.g. FBT) do not report on asynchronous components. We conclude that transferring in-person therapies to remote services starts with integrating synchronous technological components and only slight adaptations of the therapeutic framework. This is a promising and relatively easy to achieve step, which can bring great benefits, as can be seen from the various positive evaluation results. The next, more advanced, step is the integration of asynchronous components into the therapeutic framework, as it requires more adaptations in therapeutic structure and support. The successful implementation of, e.g., an accompanying therapeutic app, requires a lot more time and knowledge base to develop, evaluate and integrate into the therapeutic process.

Besides structural adaptations needed to beneficially integrate asynchronous components into therapeutic frameworks, also training is needed. Obviously, patients need to learn how to use the components properly and how to take an active role in their own health care. This process is probably guided by the therapist, which therefore, should also receive formal training before applying asynchronous components into his or her routine [31]. More specifically, this does not only hold for asynchronous components, but for all therapists providing any kind of teletherapeutic interventions [31]. Although the therapies seem to be similar to their traditional counterparts (especially at the first stage, when only minor adaptations have been applied), they are implemented in a completely different domain, posing different challenges on therapists and patients alike. Both parties need to get used to the new situation, which requires a basic understanding of the effects and mechanisms of the new domain.

If asynchronous components are included, a more detailed and carefully guided process is needed. Therapists do not only need to know how the component works, but also need to feel confident to be able to support the child with appropriate guidance so that it can benefit from the flexibility, while avoiding health threats. The sooner therapists get confident with this new and challenging situation, the sooner teletherapies get more effective and asynchronous components can be developed to finally exploit the full potential of teletherapies.

VI. LIMITATIONS

The present work has some limitations, which need to be considered when interpreting our results. As the systematic review focused on articles published in 2020, a substantial part of the body of literature is not represented in the selected articles. As most approaches evolved without the same extent of time pressure, the articles might represent more interventions using synchronous and asynchronous components beneficially. Therefore, our conclusion that only few approaches are using asynchronous components may be biased. Also, teletherapies which did not reveal positive results, such as the article by McGrath [17], are likely to not being published and therefore bias the presented approaches as being mostly beneficial.

Another limitation is the definition of children, which is not always clear from the presented articles. Some articles do not mention a suitable age range at all [4], [11], others have also included adolescents and do not separate them into distinct groups [6], [10], [11], [13], [16], [17]. This can be relevant when it comes to technological literacy, interaction opportunities and therapy organization (e.g., adolescents have a longer attention span than children).

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An overview about telecommunication and social robots for the elderly to compensate for lack of social contacts during the COVID-19 pandemic

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Abstract — **Due to an increased risk factor for complications in the elder population in case of a COVID-19 infection, measures like contact restrictions and quarantines led to a rising number of socially isolated elderly. This overview examines the opportunities and challenges of using telecommunication and social robots before and during the COVID-19 pandemic to address social isolation in care homes and at home.**

A literature review was conducted using PubMed and Google Scholar. The available literature was screened and clustered according to predefined inclusion and exclusion criteria.

Several application areas for the use of telecommunications and social robots have been identified. The challenges and opportunities of the two technologies were highlighted and the differences between the use before and after the COVID-19 pandemic were shown.

Using new devices can be a big problem for elderly, but also lack of infrastructure, usability and high costs. It is also questionable whether it is ethically justifiable to replace the important and often missing human-human interaction with robots thereby showing the challenges in the use of these technologies, which still have to be solved in the future.

Nevertheless, the literature review showed that the use of social robots and telecommunication can help against social isolation. Both technologies have been used before and during the COVID-19 pandemic and showed positive effects.

Index Terms — **COVID-19, elderly, social isolation, social robots, telecommunication**

I. Introduction

The unprecedented challenges of the pandemic caused by COVID-19 are affecting the lives of people around the world. Due to the rapid spreading of the virus, measures, like contact restrictions and quarantines, have been implemented worldwide to reduce the spread of the virus. Elder people being in more need of protection in the COVID-19 pandemic, as they are more vulnerable and have a higher risk of developing a serious or fatal course of the disease. This is related to the usually weaker immune system of the elderly. They are also more likely to suffer from chronic diseases such as heart disease, lung disease or diabetes. This leads to an increase in the risk factors for the occurrence of complications with COVID-19. Therefore, these people are particularly in focus of the measures against the COVID-19 pandemic. As a result, the number of socially isolated elder people has increased considerably. These include residents in nursing homes as well as the elderly in communities. Previous to the pandemic, Wu said in his paper that the majority of adults in communities took part in social activities, such as attending church activities, visits to senior centers or other social events. In nursing homes, social interaction like family visits are an important part of the daily routine [1].

Social isolation is defined as an objective condition, with few social relationships and hardly any social contact with other people. Loneliness, the consequence of social isolation, is understood as the subjective perception of the person affected [1]. A differentiation is made between emotional loneliness and social loneliness. Social loneliness defines the lack of active social networks. Emotional loneliness, on the other hand, defines the lack of a close emotional bond [2]. In the following, only social loneliness will be referred to in this paper.

When social isolation occurs, the human need for social connectedness is a characteristic which, like neutral, genetic or hormonal mechanisms, has a survival-securing character [3].

Various studies [1, 4] have shown that social isolation and the resulting loneliness can lead to a decrease in physical and mental health. Typical psychological effects are depression, anxiety or poorer cognitive abilities. But also the higher risk of developing Alzheimer's disease or sleeping disorders are consequences. Physical consequences are for example high blood pressure, heart disease, weight gain or a reduction in the function of the immune system [4]. These consequences also increase the need for medical care and thus the impact on the health care system that is already affected by COVID-19.

Furthermore, it has been found that people who are socially isolated continue to seek social support. One way to obtain this, especially for elder adults, is therefore the doctor-patient relationship, which is a further burden on the health care system [5].

A decreased immune function is, as already mentioned, at the same time an increased risk for a more severe progression of COVID-19 infection. These serious consequences, especially in the already high-risk group of the elderly, and the resulting increased burden on the health care system, are in contrast to the containment measures of the COVID-19 pandemic. This field of tension is reinforced by the fact that social isolation is imposed by another authority. The loss of control in the daily action is an additional stress factor [6]. Therefore, it is important to support the elderly affected by this conflict.

Digitalization, which is becoming increasingly important in everyday life and is constantly evolving, is a way of combating social isolation [7]. Technologies, in the form of video conferencing, online meetings, or even online teaching and learning have become commonplace in the workplace due to the COVID-19 pandemic. In doing so, they maintain the necessary social interaction, despite the required spacing measures. And technologies are also used in private settings before and during the pandemic to bridge the connection of physically distant people [8]. However, the technologies find little use in the elder generation, as they are mostly untrained in how to use them [9]. But in order to counteract the previously mentioned consequences of the elderly in social isolation, who are severely affected by the pandemic, technologies such as telecommunication devices are increasingly applied [8]. In addition, robots designed to reduce social isolation are increasingly being used as technology to assist in everyday life as well as in health care [10].

The paper therefore gives an overview of the use of telecommunication tools, such as video conferencing or telephony and the use of social robots among the elderly. This distinguishes it from other papers that consider only one of the mentioned technologies. This will provide an overview of how the aforementioned technology groups are being used to address social isolation among the elderly. In doing so, the paper addresses the changes in the use of technology due to the COVID-19 pandemic, looking at the challenges caused by the increased use by the elderly in their daily lives. The paper is rounded off by the question of what opportunities the application brings.

II. Material and Methods

A literature research was conducted, and the articles were analysed to answer the mentioned research questions.

A. *Literature criteria*

Inclusion and exclusion criteria were established for the selection of articles into the results of the paper. In subchapter C, the application of these criteria using the PRISMA scheme is addressed.

To ensure high quality work, only articles that have undergone a peer review process and are written in German or English language were used. As it was motivated in the introduction, only interventions aimed at combating social isolation, namely interaction and contact with friends and family, were considered. Technologies that support the daily care of the elderly have been excluded.

For this field of application, social media or telecommunications are accordingly considered as interventions. In addition, social robots have been drawn as they find more and more use in everyday life [10].

The target group of the work represents elder people aged 60 years and older. Social isolation can occur in nursing homes, as well as in private settings among the elderly living alone, so these were established as inclusion criteria. On the other hand, the elderly who live in multigenerational houses with their families, are less affected and therefore are not considered in this paper. Table 1 summarizes the inclusion and exclusion criteria.

Table 1: Criteria for literature research

	Including	Excluding
Validity	Publication peer-reviewed	Publication not peer-reviewed
Language	English, German	Any other language
Type of intervention	Social Media, Telecommunication, Social robots	Telemedicine
Intervention use for	Interaction and contact to relatives/friends	Everyday care
Target group	elderly ≥ 60 years	< 60 years
Living space	Nursing homes, alone	Multigenerational house with their families

For reasons of stringency, the terms "older people," "the older generation," and "seniors" will be replaced by "elderly" throughout this paper. Similarly, the term COVID-19 is used for "corona" and "pandemic."

B. *Search strategy*

The literature research was performed using PubMed and Google Scholar. Especially PubMed was used because this database is one of the largest medical databases that also includes technologies that are related to medicine, as this article is focused on. Furthermore, it is updated daily, free and accessible and focuses on the English language journals.

The authors created a search term for the literature research. It is formulated to perform an online search in the named electronic databases by using keyword strings with boolean operators (OR/AND). It was formulated as follows:

COVID-19 or "social robot" or "companion robot" or "social isolation" or loneliness or technology of communication and ("older people" or "older adults" or "elderly" or "nursing home").

The differences in the use of technologies before and during the COVID-19 pandemic will be considered. Therefore, the substring "COVID-19" was addressed using OR. The strings concatenated by means of OR, which circumscribe the term “elderly” in various forms, are a mandatory criterion and therefore linked to the rest of the term using AND. This can be justified by the technologies mentioned, which are to be evaluated explicitly for this target group.

C. *Analysis of the articles*

Figure 1 shows the phases of the research process based on the “Preferred Reporting Items for Systematic Reviews and Meta-Analysis” (PRISMA) [11].

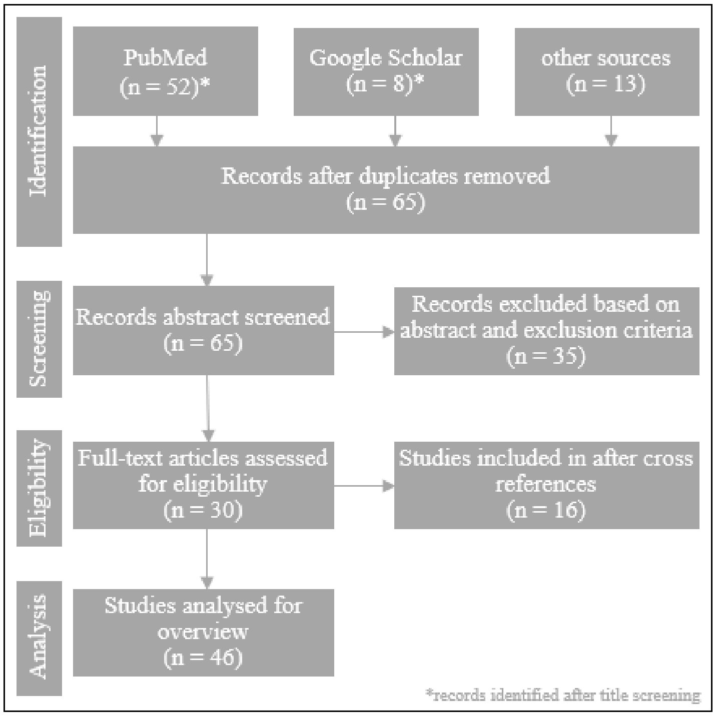

Figure 1: PRISMA Diagram research process. Example taken from [11]

In the identification phase, the sources were identified from PubMed and Google Scholar using the aforementioned search string and a title screening. After the duplicates were removed, there were 65 identified records. Subsequently, these records were analysed using the inclusion and exclusion criteria based on their abstract. 35 records that did not meet the criteria were excluded. 30 articles were therefore analysed in full text afterwards and 16 articles were added by cross referencing, the so-called snowball technique. This resulted in 46 sources consulted for the paper, which are referred to in it.

III. Result

A. *Telecommunication*

During the COVID-19 pandemic, telecommunication was increasingly used to conduct business activities (such as meetings and conferences), education (home schooling) and health consultations. They were also utilized to enable contact with other people during the time in social isolation. Systematic reviews revealed that telecommunication is used to fight loneliness [8]. In order to find out how telecommunication is used to reduce loneliness through social isolation among elderly examples are given below.

Chen and Schulz [12] investigated the impact of telecommunication on reducing loneliness through social isolation among the elderly using a systematic review. In the systematic review, they found that the use of telecommunication has a positive effect on social support, social connectedness, and participation in interest activities. The conclusion of Chen and Schulz is that telecommunication can be a tool against loneliness, but it is not suitable for all seniors. The elderly for whom it is not suitable will be examined in more detail later in the subchapter III.A.3).

In their paper Cotterell *et al.* [13] focused on intervention strategies for social isolation in old age. The outcomes of the literature review included individual, group and technology-based interventions. Individual interventions involve a pairing between an elder person and a volunteer, who are supposed to contact each other. In addition, friendship programs that pair an elderly with a volunteer with the same interests are offered. It was found that the pairing had a positive effect on the health of the elderly. Group interventions connect people who have a common interest. These can be, for example, physical activities, group discussions or therapy. The systematic review revealed that group interventions can alleviate social isolation [13]. Group-based activities are particularly suitable for ethnic minority groups. Since minorities share the same linguistic and cultural values, difficulties in interaction that they have in society can be eliminated. The sense of belonging can be strengthened by the intervention, which can reduce social isolation [14]. Technology-based interventions should be made possible by smart devices, as they can connect people and thereby alleviate the loneliness of the elderly [13]. With the help of the technology-based approach, individual and group interventions can be implemented digitally regardless of the location.

Furthermore, telecommunication can be divided into synchronous (at the same time) and asynchronous (independent of time) communication. The quality and frequency of communication with families and friends are important factors in reducing loneliness among elder people. In this context, the elderly prefer synchronous communication such as telephone calls [15]. This is because real-time interaction has been shown to create a sense of presence, connectedness and engagement. Asynchronous communication, in contrast, is more flexible for busy people who do not have as much time for a phone call. Often, asynchronous ways are used to respond to missed calls, to make up for overdue calls or to inform about unavailability for a scheduled conversation [16].

Telecommunication can be a tool against social isolation and the resulting loneliness. In the following, the technologies telephone calls, social media and video communication are listed and examined in more detail as preventive measures to support individual and group interventions in cases of social isolation. Moreover, interventions that have been changed due to COVID-19 are mentioned.

1) *Individual Intervention*

The individual interventions are also divided into synchronous and asynchronous communication. First, the individual synchronous interventions are introduced. In a study Van Dyck *et al.* [17] investigated whether the social isolation of nursing home residents can be alleviated by weekly telephone calls. For this purpose, 30 selected residents from three nursing homes were called weekly by volunteer geriatric students from the Yale School of Medicine. The volunteers received instructions for the telephone calls. The study demonstrated that the social well-being of the residents was positively enhanced [17]. Throughout Europe, Canada and Australia there are many such telephone interventions to make contact with lonely elder people in an attempt to reduce loneliness. In Ireland, the “Friends of the Elderly” program has trained volunteers who regularly contact lonely people on a part-time basis. Similar programs are the “Friendly Phone Program” in Canada and “Friends for Good” in Australia [18].

In contrast to normal conversations, telephone communication shows the elimination of visual perception. This must not be a disadvantage. Some people have an easier time communicating on the phone about emotional topics because eye contact is eliminated [19]. Nevertheless, other technological interventions can also be tried to alleviate loneliness in social isolation. The use of video calls is increasing because they allow, to see the opposite person during the call [20].

For this purpose Conroy *et al.* [9] discuss the possibilities of using new technologies to combat loneliness in the elderly in their paper. Technological progress can maintain care and connection with others despite physical distance. Solutions should be accessible and usable for the elderly. Online telephone or video conferencing can reduce loneliness caused by social isolation. Regarding this, technology should replace visits that are normally scheduled. In the wake of loneliness, the “Nextdoor App” was developed to encourage friends, family and neighbours to call or send a message to their older peers regularly.

In a cross-sectional survey study between 25 March and 11 May 2020, 132 elder people with an average age of 88.2 years (SD 6.2) were asked which communication method (telephone or video call) they prefer. 55% of those questioned tend to make telephone calls because they are more independent. Nevertheless, after the video calls the satisfaction and acceptance was high [20].

Other individual interventions are possible through asynchronous methods. E-mails allow the elderly to send messages to family and friends. E-mails offer the advantage that the recipient does not have to be present. Another advantage is the exchange of digital photos. The exchange can serve as a basis for later synchronous conversations [21].

Another possibility is offered by social media. Social media can reduce feelings of isolation, stress and panic by using them to communicate with distant friends and family. This would enable people to keep up to date with each other's situation and report on each other's health [22]. Exchanging messages can create a feeling of solidarity among the elderly, as they realize that other people are in the same situation. The feeling of solidarity can help them to feel less lonely [9].

2) Group Intervention

An evidence-based intervention for elder adults is “Circle of Friends”. This intervention involves interactive activities such as creative arts or movement training in the group. Furthermore, the group meetings are recorded so that the participants can remember the tips and feedback. Some elderly may not have the finances or transportation to participate in the group activities. As a result of the COVID-19 pandemic, group intervention was changed to teleintervention [23]. Videoconferencing not only provides benefits for lonely people during the COVID-19 pandemic. It can also be used by elderly and disabled people who are physically unable to leave home [24]. Additionally, telephone meetings are offered before and after a group meeting. One advantage of changing to a teleintervention is that participants can do the activities at home [23].

In addition, telephone and video conferencing can be used to support participation in group activities such as online worship or training sessions, thus restoring part of the routine. This in turn leads to a reduction in loneliness [9]. Brooke and Clark [25] looked at how COVID-19 changed the lives of people over 70 years during the first two weeks of social distancing. Also they tried to identify how elder people who used social media and messaging services before the COVID-19 pandemic used them to stay in touch with friends and family. Some use the group call function to communicate with several people at the same time. The use of social media and messaging services encourages contact, thereby reducing loneliness.

To find out whether video calls can improve the social isolation of residents in nursing homes, Zamir *et al.* [26] recruited 22 volunteer residents in three British nursing homes. For this purpose, monthly Skype quiz sessions were conducted over a period of eight months. Quizzes are a familiar form of entertainment in many nursing homes. The aim was to find out if it is possible to build new friendships among the residents. Friendships often develop between people who have had similar experiences [26]. Zamir *et al.* refer to Porges' social engagement and attachment theory [27] that personal interaction is essential for maintaining new and existing relationships. Video calls can be used to facilitate interactions through body language and eye contact. The best working video call method was implemented in this experiment via Skype on a TV (Android TV Box + webcam). At the beginning of each Skype session the participants introduced themself. Afterwards the residents could make small talk until the quiz started. Zamir *et al.* noticed that the competition encouraged the belonging to the nursing homes. The interaction between the subjects improved significantly from each session as they engaged in more and more meaningful small talk. Connecting nursing homes via video calls seems to alleviate the loneliness of the residents [26].

3) Challenges with technology-based Interventions

Technology-based interventions to alleviate loneliness are only effective if elder people want to use the technology and know how to use it. Moreover, access to the technology must be available, as the cost of acquisition may be too high for many elderly [9]. The position of the camera and fixing the screen can be confusing for the elderly. Furthermore, the users may find the organizational and preparatory measures for video communication to be a great effort [19].

In countries where social media and messaging applications are censored communication may not be ensured without complications [22]. Furthermore, an internet-based intervention requires an internet line with appropriate bandwidth. In rural areas, bandwidth may be a problem [9]. In a survey, around 38% of the 1075 elderly over the age of 65 years in Germany questioned said they had been in contact with their relatives and friends via the internet during the COVID-19 crisis. One third of those surveyed want to continue using their newly acquired skills after the COVID-19 pandemic [28]. In Singapore, 58% of 4549 elder residents in a survey said that they would not use the internet at all and 8% had difficulties using the internet due to their health restrictions [29]. In the UK, internet usage among people aged 65 to 74 has increased from 52% to 78% between 2011 and 2017. However, 60% of the surveyed nursing home residents said that they had never used the internet. In addition, only one-fifth of nursing homes in England provide access to the internet [13]. For the elder population, for whom internet-based intervention is not possible, available technologies such as telephone calls must be used [9]. According to the International Telecommunication Union, there were around 950 million fixed line connections worldwide [30].

The following Table *2* summarises the individual and group interventions. It can be seen that all interventions, whether synchronous or asynchronous, are dependent on an internet connection, except for the telephone calls. Besides, other devices are needed as long as the intervention is not analogue. The required devices are shown with symbols (smartphone, tablet computer and computer). In summary, for technology-based approaches internet is needed and the smart devices must be available.

	individual	group	synchronous	asynchronous	analogue	digital (internet)	device
telephone calls	x		x		x	x	☎ ▯
telephone conference		x	x		x	x	☎ ▯
video calls/ conference	x	x	x			x	▯ ▭ 💻
e-mail	x	x		x		x	▯ ▭ 💻
social media	x	x		x		x	▯ ▭ 💻

Table 2: Overview of individual and group intervention

4) *Opportunities with Telecommunication*

Nevertheless, internet-based approaches offer advantages if they are accepted by the elderly. With video communication, visual perception is possible. Hence, nonverbal signals such as gestures and facial expressions can be transmitted. Through telepresence, social proximity can be created [19]. In the future, it is expected that the use of new technologies will increase for several activities including healthcare [8]. For this purpose, the elderly should learn how to use new media.

In a study by Tsai *et al.* [31], the best method for learning how to use tablet computers was explored. Especially for elder adults the use of new technologies is a little more complicated. Using tablet computers, for example, is important for staying in touch with other people. Persons with reduced mobility benefit from this contact possibility, which can improve the quality of life. Other advantages of using tablets include access to information, such as health care, and slowing cognitive decline. It is believed that online services such as games, news, information and educational opportunities promote cognitive stimulation. As new technologies require the acquisition of several new skills at the same time, the elderly find it more difficult to learn them. In addition, they have a poorer memory, which means they need more time to learn them. Tsai *et al.* conducted interviews with 21 elder people aged 69 to 91 years. They found out that it is not only beneficial to have the support of others. It also has a positive effect to have support for setting up the new technology. The participants stated that support from family or others gave them the confidence to experiment and learn new functions. If something went wrong, they knew that they could be helped.

B. *Social Robots*

There are many different types of social robots which can be broadly defined as physically embodied agents designed for assisting and engaging in social interactions with humans in their everyday lives [32]. Furthermore systems like social robots can be capable of communicating in a human–like manner [33] and artificial agents embodied with the features of a human or animal [34]. In the following, an overview will be given of the types of robots used. Afterwards the possible applications in nursing homes and at home will be shown. Old and new challenges due to the COVID-19 pandemic have been identified, as well as opportunities in the use of social robots.

1) *Types of Robots*

Before and during the COVID-19 pandemic many different types of social robots have been tested and used to combat loneliness in the elderly population. In total eight social robots capable of being used to combat loneliness have been identified. Some have been included in studies with a COVID-19 context, but most of the newer models have not.

In a study about the possibility of robots being able to tackle late-life loneliness, social robots are separated in direct and indirect robots [35]. While indirect robots will help people to connect and bond with each other by providing the means to do so, direct robots will socialize with people in order to develop close interactions. An example for a direct Robot is “Paro”. With the appearance of a baby seal it can be used in animal therapy to patients in environments such as hospitals and extended care facilities where live animals present treatment or logistical difficulties [36]. Another robot widely used is “Vector”, a tiny companion robot produced since October 2018 by Anki, which has a large number (approximately 200,000) of active users worldwide [37]. Using a camera, a microphone array, touch sensor, a build-in processor and cloud connectivity Vector can see, hear, feel, process and react genuinely to external events. If the user chooses to set up Amazon’s Alexa on Vector, it has access to an ever-growing number of skills, like setting reminders and controlling smart home devices [38]. Vector and the similar variant “Cozmo” which have been purchasable through Amazon in 2020, are only available with limited supplies left because of the producer Anki shutting the production down in 2019. A different direct robot is “Zora” a 57 cm tall humanoid robot which can be used for rehabilitation and recreational assistance with exercise, playing music, story-telling as well as playing interactive memory and guessing games [39]. Also often in use is the humanoid robot “Pepper”, a social robot that can interact with humans through conversation and its touch screen. It could keep up a decent conversation on a chosen topic — be the subject whatever a resident desire — especially as they develop technologically in the future [35].

While the already named robots are part of the direct group of robots, an examples of indirect social robots are the telepresence robots "Temi", "Double" and "Giraff", designed to enable human interaction from a distance and thus enable residents of nursing homes to keep in touch with people outside the facility or even remotely attend events such as concerts, exhibitions, courses and more [35].

2) *Usage in nursing homes and at home*

Kidd *et al.* [40] used the robot Paro in two nursing homes and found positive effects. In weekly meetings, several inhabitants were brought together in their living room, with Paro being first introduced and then put in the middle, either activated or deactivated to see how the inhabitants would interact with the robot. The results showed groups with a Paro were more active and interactive than groups without the robot. Some users even began a relationship with Paro in which they saw it as dependent on them. Very often they are or were pet owners. Questionnaires revealed that Paro did effectively evoke memories of pets. In fact, many conversations about Paro turned into discussions about other animals, often cats and dogs. On the negative side however, one nursing home had to be excluded from the study, due to the staff being unable to provide enough opportunities for interactions with the robot and other inhabitants since Paro is not a great entertainer by itself.

A exploratory study by Odekerken-Schröder *et al.* [37] that used the smaller companion robot Vector collected online contributions posted between January 30 and June 3, 2020. For users Vector seems to be a way to face off isolation by receiving social utility. They asked Vector to provide information on the weather, time and on the COVID-19 pandemic. Interactions with Vector are also described as providing social connectivity to users in different situations sharing daily activities as lunch and dinner as well as enjoyable activities. Some users even expressed a strong sense of social identity (attachment) to Vector and describe how they talk to or about their robots. An emotional attitude emerges when they perceive Vector as a child or at least as part of the family.

In their field study in 2015 Melkas *et al.* [39] focused on the real-life implementation process of the care robot Zora in elderly care services in the city of Lathi in southern Finland. The implementation period lasted from December 2015 to April 2016, where the robot was introduced into two care homes and a geriatric rehabilitation hospital. Although this study was performed before the COVID-19 outbreak, the results are similar to a newer study by Huisman and Kort [10]. Based on the positive effects of the robot Paro shown in several studies, the use of robot Zora was monitored and evaluated in 14 nursing care organizations in the Netherlands from 2015 to 2017. Students and research staff visited the locations and conducted interviews and observed the activities with Zora, while using questionnaires to gather additional data on the usefulness, satisfaction and ease of use, as well as the effects and work experience. The results in both studies show a positive effect as the inhabitants showed more stimulation, leading to spontaneous participation. Even agitated or withdrawn participants showed positive responses when being with Zora [39].

3) *Challenges with Social Robots*

Although the feedback was mostly positive, some barriers to the continuous use of the robot, like battery life, software failures and a stable internet connection were mentioned by staff members. Despite Zora already having basic activities programmed, they were perceived as too limited. When trying to expand the activities the employees were having trouble with software updates and uploading new activities to the robot. It was also mentioned that the robot had to be supervised all the time and the ethical concerns raised by employees. As Zora is quite small, the robot was seen as a toy and thus the meaningfulness of the practice was sometimes lost without an employee explaining the exercise. Similar problems have been identified with the robot Paro. The robot presents itself as a baby seal, which led some inhabitants to express their desire to put Paro in water, which would be dangerous and destroy the robot. Paro was also too heavy to be picked up and moved around by the mostly frail and elderly inhabitants, which limits its use in the nursing home itself. Some reactions by inhabitants included irritation, reserve and even fear. A client stated that it goes too technical, it is the human contact that is missed and that is more important than some toys [10].

Ethical issues should be considered, as human-robot interaction is not designed to replace human contact but should be seen as a possible addition [28]. The appearance and behaviour of robots may lead people to think that they are a suitable replacement for human or animal companionship and interaction. This kind of personalization plays an important role in the design of social robots [41]. There is a risk here of inadvertently misleading and misguiding the elderly. People tend to anthropomorphise objects and imagine that these objects are capable of more than they are [35]. The objectification of elder people can occur when the use of social robots is justified by the needs of the care facility and relatives rather than the elderly themselves. Social robots would then be a solution to a lack of staff or relatives' unwillingness to visit the elderly at home or in the institutions [42, 43]. A similar problem exists with telepresence robots, which offer elder people the possibility to stay in touch with relatives. However, some researchers [44] warn that telepresence robots reduce human contact because it is easier for relatives to contact them virtually instead of being there themselves.

As stated by Hung *et al.* [45] one identified barrier to the uptake of social robots is cost and added workload to staff. As Paro was often used individually or in small groups, the cost of 6000$ in 2019 was brought up as a barrier to use in care settings. Additional costs due to maintenance, cleaning and repairs can lead to concerns, as most healthcare organizations have to purchase their own. Newer robots like Vector and Cozmo made for use at home were cheaper with a price of 300$ and were therefore more widely used [37].

The usage of shared devices can be a problem in nursing homes and can accelerate the spread of viruses and bacteria. Though not a key point in older studies, a new study about the microbial contamination and efficacy of disinfection procedures of companion robots in care homes shows that after group sessions, the microbial load was above the acceptable threshold of 2.5 CFU/cm^2. Colony counts were measured by colony forming units per square centimetre (CFU/cm^2). Samples were collected using contact plate stamping and evaluated using aerobic colony count and identification (gram stain, colony morphology, coagulase agglutination). Furrier pet robots just like Paro demonstrated particular unacceptable levels. If not cleaned properly the bacteria found in the samples can present a risk to human life. The time needed to clean these robots might be a factor as staff has already very limited time as shown above [46].

4) *Opportunities of Social Robots*

Studies already conducted have identified not only challenges but also opportunities for the use of social robots. Real animals offer benefits for the well-being of the elderly but are not always applicable in treatments. Robots require less care and are safe to use. They have been shown to reduce stress, anxiety and antipsychosis in the long term. Paro has been highlighted in the role of an icebreaker between staff and residents and as a social mediator or impetus for social interactions between residents in nursing homes [45]. Just like Paro, Zora`s positive effects on clients are one of the success factors of the care robot, especially with the activities of dance, singing and games [10]. Interactions with a social robot can offer opportunities for people to deal with the challenges of social distancing. The robot Vector mitigates loneliness and can restore some sense of presence of others during social distancing. As a form of supportive relationships, social robots can provide utility, bring joy and enhance feelings of intimacy [36].

IV. Discussion

In the following, the paper is critically considered and discussed. Thereby the method of the paper, as well as the results, thus the use of social robots and telecommunication tools are compared.

A. *Method consideration*

On the one hand, the systematic review brings up an unprecedented level or compilation in the overview of technologies against social isolation. However, the methodology of the paper also contains a limitation, which is explained below.

Due to the search result of 7457 hits based on the search string, additional title screening was performed for narrowing down the literature search. This is because of the goal of the paper and thus the formulation of the search string of comparing the use of technologies during as well as before the COVID-19 pandemic. However, this approach did not allow for further specification and may have resulted in a less specific data base, which can be seen as a limitation of the work. In the authors' view, though, the results of the work provide a good overview and are therefore to be regarded as sufficient.

B. *Main findings summary statement*

The literature review showed that the use of social robots and telecommunication can help against social isolation caused by COVID-19. The use of the technologies differs in the way social isolation can be reduced in individual and group interactions [13]. On the one hand, robots can act as communication partners. On the other hand, they can also be used like telecommunication to maintain the relationship to social contacts. They represent a link between two people [37].

The different living situations of elderly people, such as residential groups, nursing homes or their own apartment in a community, lead to different requirements. The benefits of these remedies against social isolation and thus the consequences and risk factors of loneliness in pandemics have been demonstrated in the evaluated studies. Based on the studies in this paper it could be established that social robots are mainly used in nursing homes. In contrast, the use of telecommunication is also found in private households. It is assumed that this is due to the different investment costs of the technologies [45].

The deliberate use of video communication is particularly noteworthy. Through video calls, body language and eye contact can be transmitted better as emotions between the communication partners and create a feeling of real communication [33]. Especially for elder people, who are physically restricted and thus do not have access to many social activities, a social environment is created, even outside the pandemic [29].

To reduce the social isolation of the elderly, the quality and frequency of communication is an important factor [15]. Synchronous communication gives elders a sense of presence and connection with their communication partners [16]. Although the elderly prefer this synchronous type of communication, such as video telephony, asynchronous communication offers advantages for busy family members and friends. For asynchronous communication such as emails, the communication partners do not have to be present at the same time [21]. A balanced compromise between synchronous and asynchronous communication should therefore be attempted to accommodate all parties. Further research is needed to analyse this balance.

Nevertheless, the benefit of these applications is only given if they are used effectively. Access to new technologies is not as widespread in the elderly as it is in the younger generation. The elderly did not grow up with them and are therefore often not prepared to embark on something new. In addition, there are problems with the operation and installation of the devices. A possible support, especially from family members, can minimize these problems [31]. However, there are other difficulties that should also be considered, e.g., with the help of the installation on site, due to the COVID-19 pandemic.

The use of the technologies is strongly slowed down by the investment costs, especially for robots. In addition, there are also maintenance costs that can be incurred on an ongoing basis. These include costs for regular cleaning of the equipment. Especially in nursing homes where technologies are shared, hygiene is essential to reduce the spread of viruses and especially the COVID-19 germ [46].

Scientists, caregivers and users themselves expressed ethical concerns about the use of robots. According to them, the disproportionate use of social robots risks further reducing human-human interactions that are already limited or absent due to social isolation. It would also be possible to fake meaningful interaction for elderly by means of robots and to reinforce an unwanted objectification of the elderly [35, 41–

44]. In contrast, the positive effects of social robots have been demonstrated in various studies. Both in nursing homes and when used at home, an effect has been demonstrated [10, 37, 45]. Weighing the costs, ethical challenges and benefits of this technology is a task that cannot be answered based on the available studies in this overview.

Also the conditions of the technologies can be an obstacle in the introduction. Communication via the internet requires a certain amount of internet bandwidth. This cannot be guaranteed everywhere. Especially in rural areas, where the expansion of the internet network is not always possible [9]. The availability of the Wi-Fi in large nursing homes is often not available everywhere or even not at all [13]. Both the introduction and the expansion are connected with a great effort and the resulting costs [9]. The regular use of telephony is therefore a cost-effective and widespread alternative to counteract social isolation [17–19].

Comparing social robots with telecommunication interventions, the biggest difference is that social robots are mainly used in nursing homes. The reason for this seems to be the cost. Nevertheless, all interventions require the appropriate equipment as well as an internet connection, except when making telephone calls. The use of telephones is preferred among the elders because telephones are available, whether in the nursing home or at home, and the elders can use them without assistance. In contrast, a common feature is that the elders might need help in setting up as well as operating the technologies in order to reduce the inhibition to use the interventions. It seems, that with support, the acceptance to use the devices is available. All technologies showed a positive effect when used to reduce social isolation. However, it is not possible to say which intervention, social robots or telecommunications, is most effective. Further studies need to be conducted for this purpose.

Social isolation was already a social problem before the COVID-19 pandemic. Due to the measures taken against the spread of the infection, the problem has grown worse [18]. At the same time, digitalization provides new perspectives in everyday life and offers opportunities to compensate for social isolation [8]. The use of new technologies can be therefore essential, especially for elder people. The elder generation should deal with the new technologies now as well as in the future. As a result, the elderly may actively reduce health problems, resulting in fewer risk factors. Hopefully, the economic impact and the burden on the health system can be reduced. Social isolation will most likely continue to be a social problem in the future.

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Systematic review on the positive and negative influences of social media on mental health of adults during the COVID-19 pandemic

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Abstract—**Introduction: The COVID-19 pandemic represents a comprehensive health crisis entailing both physical as well as psychological consequences for the world population. Particularly during social distancing and isolation, the lack of social interaction in person is compensated through increased social media use. This brings both benefits and harms, which require to be investigated.**

Methods: 34 papers from 2019 and 2020 were systematically reviewed regarding positive and negative impacts of social media on mental health during the COVID-19 pandemic. Different use cases of social media – like the dissemination and consumption of information or the provision of social support – were evaluated regarding opportunities and risks.

Results: The consumption of COVID-19-related news spread via social media is correlated with negative mental health effects, especially anxiety. Yet, social media platforms can serve as a space to support the community and encourage health professionals. Furthermore, they can be a valuable tool for governments and health authorities in order to provide a base for scientific information combatting misinformation and a news channel for changing disease measures.

Conclusion: Future research should focus on longitudinal studies assessing long-term effects of social media in conjunction with the pandemic and the subsequent disease control measures.

Index Terms—social media, mental health, COVID-19, pandemic, systematic review.

I. Introduction

THE outbreak of the COVID-19 pandemic was the start of a global health crisis. Whereas the physical danger of the Severe Acute Respiratory Syndrome (SARS) caused by the SARS coronavirus 2 (SARS-CoV-2) is apparent, the global mental health situation seems rather unclear. Due to the lockdown and the associated consequences like social distancing and mobile work, people lose their daily face-to-face contacts. In times of increased isolation or even in quarantine, keeping in contact with other people gets increasingly difficult. As human beings are essentially social, it is unbearable for many people to be isolated. In addition to that, stress and uncertainty about the future, e.g. fear of losing one's job, can lead to serious mental health issues, which in turn can even lead to suicidal behavior [1]. Therefore, it is necessary to shed light not only on the physical outcomes of the COVID-19 pandemic but also on the psychological consequences.

When it comes to social distancing and especially isolation, one of the coping strategies is to compensate the lack of social interaction and bypass distance through social media. In fact, in the era of COVID-19, using information and communication technologies to socially connect via the internet has become vital [2]. The advantages are apparent: social media platforms provide a space to connect with others, for entertainment and for making information easily accessible, which explains the increased usage during the lockdowns [2]. On the downside, they can be intentionally abused, e.g. serving the purpose of discrimination [3]. Furthermore, unregulated misinformation spreads quickly on these kinds of platforms, which can have an adverse impact on the well-being of the end users. In the worst case, social media can cause an "infodemic" – an extensive distribution of false or misleading information [4].

As the current pandemic itself can be regarded as a "mental health disaster" [5], the additional and considerable impacts of social media on mental health play a major role in the worldwide battle against COVID-19. There are four existing reviews, which already addressed aspects of social media and mental health during the pandemic but showed different restrictions. On the one hand, they have population constraints: one was solely limited to the well-being of clinicians [6], whereas another merely concentrated on athletes [7] rather than the general public and social media end users. On the other hand, they focused on the SARS disease [8] or suicide rates [9] scarcely covering the influence of social media on mental health. Furthermore, there is a great range of reviews (ten), which only depicted either the harms or the benefits of social media on mental health [1, 10–18]. Overall, the current reviews appear to be considerably one-sided suggesting that a more comprehensive paper is required. Hence in this systematic review, we summarized the positive and negative influence of social media on mental health of adults during the COVID-19 pandemic 2019/2020.

II. Background

The terms "social media" and "mental health" are used in this paper as follows.

A. *Social Media*

Based on the fast-evolving nature of technology, it is difficult to strictly define social media. In 2015, a literature review was conducted [19] in order to find specific components that different social media services have in common. The auhtors define social media services to be internet-based applications that allow for user-generated content and the creation of platform specific profiles. Furthermore, social media services allow individuals or groups to form networks online.

Social media apps separate themselves from traditional media (e.g. newspapers, television and radio) due to different ways of interaction with information and other users. While the user's role in relation to traditional media is mostly of a consumer, on social media platform it is more bidirectional with the user also creating content. This separation can be further subgrouped based on several dimensions regarding the role they play, contributing to the available information on their chosen platforms [20]. Users can be managed by individuals, organizations or virtual entities, so-called bots. They can actively create, share and interact with other peoples' content or passively consume it. Whether this subtyping adds additional value to a study must be individually assessed.

B. *Mental Health*

Next to the physical harm of COVID-19 cases, the pandemic has "serious effects on daily living, social life, economic status, and psychological well-being of both affected and unaffected populations" [21]. There are both immediate and long-term psychological effects. These effects can be non-pathological indisposition or pathological mental illness. Non-pathological indisposition can be any form of mental distress, e.g. a subjective feeling of being lonely, isolated and exhausted or a mild depression or anxiety. Among the pathological mental illnesses, the effects of pandemics concentrate on high levels of depression, anxiety, insomnia, secondary trauma, and suicidal behaviour [21]. Furthermore, it should be differentiated between people with mental health issues and people who were mentally healthy before COVID-19 started.

III. Methods

A. *Inclusion Criteria*

For this systematic review, we involved papers including preprints, which have been published within the last two years (2019, 2020) since the COVID-19 pandemic is a current issue. Furthermore, we examined articles written in English, yet with no restriction to the population nationality. We focused on the influence of social media on the mental health of adults to generate a critical mass of evaluable and comparable articles (instead of, for instance, also including papers about children). In so doing, all social media platforms were included and both positive and negative influences were regarded as relevant.

B. *Exclusion Criteria*

We excluded any article not matching the following criteria:

- published before 2019
- no full text available
- about children or adolescents
- not about the COVID-19 pandemic
- not about the social media influence on mental health.

C. *Search Strategy and Data Extraction*

The systematic literature search for this review was executed from 07th to 21st November 2020 applying the inclusion of all three search terms "social media", "mental health" and "covid-19". We mainly used the search engine PubMed in order to meet the requirement of combining both technological and medical information. Additionally, we searched on IEEE Xplore to include another technological database but found only one additional article.

Many of the studies found rest upon surveys and since most of them used social media platforms to recruit participants, the methods description frequently mentioned the string "social media". This was often not detectable while screening the abstracts. As a result, we excluded many of the papers after full-text screening. In addition, there was a range of papers using social media as an analysis tool to find indications of the mental health state of the users – we excluded them, too, because they did not comply with our eligibility criteria.

For the data extraction, we formed three categories based on the main purposes of social media use with an impact on mental health: *provision and use of information*, *social support* and *further use*, of which the latter summarizes other considerable use cases. Based on these three categories, we assigned the studies to each of us to compile the results paragraphs B. – D. as follows.

IV. Results

A. *Literature Selection and Focus*

Finally, 34 of the studies were considered relevant and thus, were included in this systematic review. The literature selection process is shown as a PRISMA diagram [22] in Figure 1.

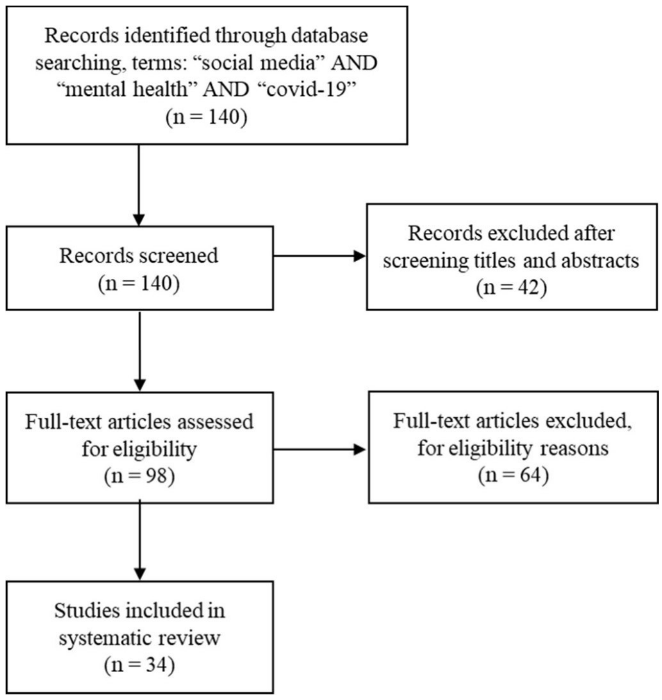

Figure 1 Process flow of review literature selection.

In the 34 reviewed papers, Facebook, WhatsApp and WeChat were the most commonly surveyed social platforms. The usage of these platforms increased for several reasons during the COVID-19 pandemic [23]. The major purposes of social media use with an impact on mental health – *provision and use of information*, *social support* and *further use* – are elucidated in the following three paragraphs.

B. *Provision and Use of Information*

While social media has many use cases, dealing with information (e.g. creation, dissemination and consumption) is a major one. The following section covers how social media regarding the provisioning and use of information can act as a risk factor or means of resilience for adverse mental health effects.

In the selected literature, a greater number of the reviewed studies investigate negative over positive connections between social media use and mental health, but social networks can play an essential part in coping with a crisis situation when they can be used as a source of factual and positive information [2]. With this in mind, social media can become a vital tool for governments and health authorities in order to disseminate factual information.

In this way, the benefits of providing an official WhatsApp information channel in Singapore were investigated [24]. A free and voluntary subscription would provide the citizen with twice-daily updates on the current situation. The messages included information about case numbers, statements regarding rumors, novel knowledge about the disease, restrictions in order to control the spread, as well as responses to recent events, like panic buying. While a correlation between time spent consuming COVID-19-related information and depression, anxiety and stress symptoms was found, the use of the official WhatsApp channel emerged as a protective factor. This can be advice for governments, as well as health authorities, to include social media as a tool when fulfilling their responsibility of sharing information and providing support in a consistent and up-to-date way. Involving the government in social media based dissemination of factual information is also recommended by other findings [21, 25], as uncertainty can be a large contributing factor of anxiety [26].

While these proposed solutions or recommendations can play a vital role in disseminating critical information and combatting misinformation, their implementation is met with challenges. Some of them are user awareness and acceptance of the provided service. While awareness can be increased by advertisements, the causes of lacking acceptance are less clear. The adoption rate of the official WhatsApp channel at the time of the survey was roughly ten percent of the population and the fifth most popular news source after websites and apps explicitly for news, Facebook, WhatsApp in general and television [24]. It is unclear however, if this was a matter of the novelty of the service, technological hurdles or other causes, and no additional investigation in this regard was made in the respective study. An analysis of a questionnaire with 23,756 participants in Russia highlights a "low overall trust in state and local authorities, and perception of country readiness" [27], which further sheds light on possible limitations regarding the acceptance of provided services.

In contrast to the positive effects of the distribution of necessary information in a crisis, its dissemination may entail several negative outcomes. Overall findings, during the early stages of the coronavirus outbreak, are consistent that increased social media exposure is correlated with increased anxiety [28–30] or other adverse mental health effects [31, 32]. Particularly the consumption of negative news, e.g. exposure to disasters or reports about hospital bed shortages, has a negative impact on the consumer's mental health [33, 34]. Additionally, information regarding shortages of goods can lead to panic buying, as was observed in the beginning of the pandemic [35].

A major downside of social media's fast spread of news is misinformation. Not only can false claims induce further stress or panic [4] but misleading information regarding treatment or disease prevention can be physically damaging through application of false medication [23]. On the other hand, greater consumption of social media is associated with a higher perceived risk of being affected by the pandemic [36] and could thus motivate people to engage in further protective behavior, like staying at home or wearing masks.

Despite most studies evaluating a general connection between social media usage and mental health effects, some focus on differing outcomes based on subcategories regarding media types and subgroups of social media users. Here, active social media engagement is associated with negative effects [33, 37]. Consumption of unregulated social media, i.e. platforms where the creation and sharing of content is not or only barely moderated, is found to be a greater risk factor than the use of traditional media in order to get information [33].

An additional factor relating social media to mental health effects is the amount of time spent following COVID-19 news. A strong correlation of news consumption duration and anxiety levels has been found [27]. Anxiety levels were measured using the State and Trait Anxiety Inventory [38]. It has been suggested to classify participants to show significant symptoms when scoring above 40 in the possible range of 20-80 points, while other sources recommend a higher threshold of 55 points [38]. With a median score of 52 in the S-Anxiety subscale, media consumption of one to two hours leads to a 5.46 score increase, media consumption of two to three hours and more than three hours to a 7.06 and 8.65 increase respectively, compared to participants with less than 30 minutes of daily exposure. Despite the uncertainty of the cut point, the increase of scores based on time spent following COVID-19 related news is significant and generally supported by other studies, but with varying thresholds: Contrary to the proposed 30 minutes limit other findings advise a threshold of 60 minutes [39], 2.5 hours [40], or between two and four hours [41]. When analyzing survey responses, between one quarter and one third of participants spent more than two hours daily learning about COVID-19 [42–44] and would thus be under higher risk of adverse mental health effects.

In this way, disseminating and consuming information through social media entails both risks for individuals and opportunities for authorities in regard to coping with the

COVID-19 pandemic.

C. Social Support

Another important use case of social media is staying in contact with one another and getting social support. Social support is defined as "the individual feeling valued and cared for by their social network as well as how well the person is embedded into a network of communication and social obligation" ([45], cited in [46]). As social interaction is a basic human need, many are struggling with the isolation measures. Digital social platforms are the only opportunity to communicate with others in times of self-isolation and quarantine [47]. Due to this many people increased their social media use to stay connected [23].

People often compare their opinions and abilities to those of other people with the aim of self-evaluation. This is called social comparison – when happening over social media it is called online social comparison. In stressful situations, people tend to compare themselves to others who are worse-off. Because in times of COVID-19 most of the social media users share the same condition, the comparison can help to see oneself in a positive light. This can lead to greater life-satisfaction and lower distress-level. In pre/post-quarantine comparison it has been shown that, before the lockdown, an excessive online social comparison was linked to more loneliness, depression, anxiety, and stress [47]. During the lockdown, it was only linked to more depression. This shows that social media use in times of a pandemic has other effects on mental health as using social media in normal times [47].

Besides the social comparison, social media can offer two other types of social support: emotional support and peer support. Emotional support is a form of interacting with other social media users in order to build compassion and trust, while peer support describes social support, which results from the feeling of belonging to the same group as others do [46].

In the context of emotional support, a study found that a moderate social media use (the intensity of use was valued by the study participants themselves) can help to manage stressors so the users can benefit from it, while an excessive use contributes significantly to more severe depression and more severe secondary trauma [46].

Another study revealed significant positive associations between social media use and anxiety, while connecting via video calls with other people (which is also a part of social media usage) had no significant associations to anxiety [23].

In the context of peer support, there is a project started by mental health professionals [5]. The conductors created a WeChat group with healthcare professionals to give them psychological support when they must deal with COVID-19 on the frontline. This form of peer support service has been accepted by the healthcare professionals and the authors of the study suggest to use this model in other interventions too [5].

As social media can provide social support, it can be a warn sign if someone spends too much time needing this support. In one study, it was discovered that psychological abuse of women increased during COVID-19 and that affected women frequently use social media as a coping tool [48].

The mentioned studies are mainly carried out with people who were mentally healthy before COVID-19 started. A study with people with mental health issues before COVID-19 found that there is an association between coping with the pandemic and staying in contact with other people [49]. Those, who coped poorly with COVID-19 had less contact with other people trough media [49]. The effect of social support via social media to people with pre-pandemic mental health issues as shown in [49] is similar to the effect to people without pre-pandemic mental health issues as shown in [46, 47].

D. Further Use

Next to the examples given in B. and C., there are other potential utilizations of social media with an impact on mental health. One application field becomes manifest in online debates: other than giving and receiving information or support, social media can serve as a platform to discuss current topics as well as exchange different views and ideas [24]. However, the constant discussions about the pandemic status on social media can lead to emotional exhaustion of the end users [50]. Notably at the beginning of the outbreak, physicians frequently discussed the application of personal protective equipment as well as prophylactic medications sharing their opinions and experiences on social media. While the previous chapter particularly elaborated on the positive influences of contact via social media, discrimination can be another downside of it. A study focusing on neurosurgeons found that more than 30% of the respondents admitted to receive discriminating or threatening messages via social media, which can be attributed to the general fear of people that health care workers could carry the infection into their neighborhood [3].

During the pandemic and social distancing, social media has additionally proven appropriate as a platform for education as well as knowledge sharing. This particularly comes into use when physical exchange is reduced. For instance, health authorities in China early on provided online education services regarding mental health and the transmission of disease by sharing messages through social media platforms [51]. As a result, patients with more frequent social media access were more likely to benefit from online education. It was further discovered that physicians find social media helpful for decision flow, planning and updating practice modifications [3].

Political leverage constitutes another field of social media usage. A study found that there is a significant link between social media use and health behavior change [46] suggesting that social media cannot only serve the purpose of education but also apply as an effective tool of influence. It comes apparent that the more people engaged in social media during the COVID-19 outbreak, the more likely they changed their behaviors. However, the health information shared on social media platforms had only a strong impact on health behaviors if the information was embedded in an emotional touch or the influence of acquaintances and friends [46]. This is affirmed by another study stating that social media increase perceived risk and safety behaviors [21]. While governments are recommended to engage in calming the population and providing one source of truth via social media (see B.), there is a risk of fueling politically motivated conspiracy theories. These are "attempts to explain the ultimate causes of significant social and political events and circumstances with claims of secret plots by two or more powerful actors" [[52–55], citied in [56]]. In combination with unregulated social media, the problematic theories become directly assessable, distributable and therefore a potential health risk. A current study found that there is a positive relationship between holding conspiracy beliefs and both the preference for social media over legacy media as a source of information and the frequency of checking social media for COVID-19 news. The conspiracy beliefs most strongly associated with social media (especially YouTube) are a connection between COVID-19 and 5G as well as doubting the existence of the coronavirus. Moreover, the study found a significant negative relationship between the use of social media as a COVID-19 information source and the engagement in health-protective behaviors. Social media usage appears to be the most powerful predictor for conspiracy belief [57]. The role of social media as a disseminator of conspiracy belief goes further: a 2020 study found that belief in a COVID-19-related conspiracy theory is associated with the unstable mental health of health care workers. As a result of the study, conspiracy belief constitutes a marker to identify mentally vulnerable people – they are more likely to search, discuss, and distribute pandemic-related conspiracy theories via social media [58].

V. Discussion

Like any information and communication technology, social media primarily constitutes a tool, which can be used as well as misused in many ways. The corresponding positive or negative effects depend on the motivation of the end users on the one hand, and on the pursued political framework and governmental interventions on the other hand. This review gives an overview of the positive and negative influences of social media usage on the mental health of adults in the course of the COVID-19 pandemic. Various current studies found a significant correlation of social media use and mental health issues. In contrast, there were examples indicating that social media use can have a positive impact on the mental state. Some studies have shown that the different kinds of social media usage (e.g. seeking information or emotional support) can have diverse effects on mental health. Governments and health authorities can utilize social media to promote the dissemination of scientific information and disease containment measures. They can also be used by individuals to connect and support each other, especially during lockdowns.

There are some limitations of our review. Many papers focused on a certain region or country, which may introduce cultural bias. Besides, most studies were conducted in a cross-sectional manner, evaluating only a snapshot of time, which limits the ability to reason about causality. Even though most studies correlated social media use and mental health problems, this can be interpreted both ways. Social media use could lead to reduced mental health, preexisting mental health issues could change the way social media are used or a combination of both could be the case. More longitudinal studies are required to provide insight into changes over time as well as the impact of certain events, like a large rise in case numbers or a tightening of restrictions. Furthermore, the population sampled by work reviewed in this paper is limited to people using social media via the internet – this is a prerequisite for the subject of "social media", plus, a lot of studies are based on e-questionnaires due to the physical distancing measures. However, this is a biased representation of the privileged demographic group of certain countries and cannot be generalized to the whole world's population. The mental health situation of disadvantaged people may differ from our results. Additionally, many studies have used the snowball sampling method for recruiting study subjects. This method is susceptible for many biases, e.g. people with more friends or more social media contacts are more likely to get involved in the study. The limitations may resolve by conducting more comprehensive studies in this field.

As an outlook, the potential of using popular social media platforms to provide guidance and support for the mental health of people with mental illness could be further leveraged. We suggest that the governments and health authorities engage in social media campaigns in order to promote positive mental health and provide both easy, verified information access and social support. For professionals in healthcare, this additionally suggests the need of clear guidelines to determine how to act on social media [59]. This applies not only to the COVID-19 pandemic but also to potential future pandemics.

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VII. Declaration of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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