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Review

Socially Assistive Robots Helping Older Adults through the Pandemic and Life after COVID-19

Cristina Getson [1,*] and Goldie Nejat [1,2,3,4]

[1] Autonomous Systems and Biomechatronics Lab, Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Road, Toronto, ON M5S 3G8, Canada; nejat@mie.utoronto.ca
[2] KITE, Toronto Rehabilitation Institute, Toronto, ON M5G 2A2, Canada
[3] Rotman Research Institute, Baycrest Health Sciences, Toronto, ON M6A 2E1, Canada
[4] Canadian Institute for Advanced Research (CIFAR), Toronto, ON M5G 1M1, Canada
* Correspondence: cristina.getson@mail.utoronto.ca

Abstract: The COVID-19 pandemic has critically impacted the health and safety of the population of the world, especially the health and well-being of older adults. Socially assistive robots (SARs) have been used to help to mitigate the effects of the pandemic including loneliness and isolation, and to alleviate the workload of both formal and informal caregivers. This paper presents the first extensive survey and discussion on just how socially assistive robots have specifically helped this population, as well as the overall impact on health and the acceptance of such robots during the pandemic. The goal of this review is to answer research questions with respect to which SARs were used during the pandemic and what specific tasks they were used for, and what the enablers and barriers were to the implementation of SARs during the pandemic. We will also discuss lessons learned from their use to inform future SAR design and applications, and increase their usefulness and adoption in a post-pandemic world. More research is still needed to investigate and appreciate the user experience of older adults with SARs during the pandemic, and we aim to provide a roadmap for researchers and stakeholders.

Keywords: socially assistive robots; older adults; health and eldercare; human–robot interaction; COVID-19 pandemic; social isolation; post-pandemic

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1. Introduction

The world's population is aging, which is placing a strain on caregivers to support and care for the elderly as they age. By 2030, it is predicted that there will be a worldwide shortage of more than 100,000 caregivers [1]. For the first time in history, the number of people older than 64 years old in the world has surpassed those younger than 5 years old [2]. By 2050, the share of the global population older than 65 is expected to rise to 16%, from 9.3% in 2020 [3].

With the advent of the COVID-19 pandemic, opportunities for social relationships, especially for older adults, have decreased. Social isolation and loneliness have spiked worldwide [4,5], threatening well-being and representing a major determinant of health, including the increased risk of premature death [6]. The prevalence of loneliness among older adults living in long-term care is at least double that of those living in communities; during the pandemic, residents were isolated from visitors to reduce the risk of spreading the virus, and group activities and communal dining were halted, which in turn increased isolation and loneliness among residents [7]. The pandemic offers a "unique opportunity to envision, pilot or implement novel technological solutions that could have a lasting impact on the health and well-being of older adults" [8]. Socially assistive robots (SARs) can be used to provide a safe means of interaction for older people. They can also be easily sanitized regularly. These interactive robots behave in a lifelike manner, they can recognize and interpret verbal and non-verbal communication modes such as speech, gestures, and eye contact, and respond appropriately using their own sophisticated emotional intelligence and conversation abilities [6].

Data on mental health repercussions from the 2003 Severe Acute Respiratory Syndrome outbreak indicated that stress, social disengagement, and anxiety led to a number of unfortunate deaths by suicide among the elderly [9,10]. The COVID-19 outbreak is of particular concern in hospitals and healthcare facilities, as many long-term care facilities went into lockdown, restricting visitors and family members from seeing and interacting with residents. The psychological impacts of quarantine on the elderly and on healthcare workers, such as confusion, fear, anger, grief, and anxiety, can be long-lasting [11]. The age-related case fatality rate of COVID-19 in people over 80 years old is at 14.8%, with the most serious cases found in people with comorbid conditions [12]. In Canada, COVID-19 resulted in a significantly disproportionate number of outbreaks and deaths in both long-term care and retirement homes [13]. During previous pandemics, such as Severe Acute Respiratory Syndrome, Ebola, and avian flu, robotics were used to mitigate the risk to healthcare workers, by serving as telepresence communication systems and performing clinical activities, such as the delivery of medication and meals, and transporting bio-hazardous materials [14]. Placing robots in healthcare facilities can help to lower staff workload, thereby increasing the overall efficiency of these facilities [12] and minimizing the impact on residents.

When using SARs together with general information communication technologies (ICT), pre-COVID-19 studies showed that depression can be reduced, through engaging seniors in daily interactions with a robot [15]. Robotics has also been used to increase independent living, help reduce social isolation and enhance well-being by increasing social connectedness. The uptake of assistive technologies, such as robotics, sensors, computers and the Internet, by older adults was shown to have a positive impact not only on the individuals, but also on those who take care of them, such as healthcare professionals and family members [15].

The COVID-19 pandemic is showing that humans and robots can work together to keep people safe; technology has not replaced in-person care, but rather reduced the number of times healthcare staff had to be in direct contact with residents [16].

In this paper, we provide the first targeted review of how exactly SARs are helping older adults and caregivers during COVID-19. In Section 2, we discuss the methodology and procedure we utilized to conduct the literature survey. In Section 3, we outline the crisis the pandemic has caused in long-term care homes, and in Section 4, we identify and discuss commercially available SARs currently deployed that provide assistance to older adults. Then, in Section 5, we investigate the main influences on the social perception of robots and how or if these perceptions have shifted due to the pandemic. Furthermore, in Section 6, we investigate and discuss the crucial enablers and barriers to the implementation of SARs. Section 7 provides a roadmap with strategic insights on potential future research directions for SARs in a post-pandemic world based on the lessons we have learned during COVID-19. Lastly, Section 8 provides concluding remarks. We focus on ways in which SARs can be used to improve the well-being of our older vulnerable population as well as safeguarding them against COVID-19 and other future outbreaks.

2. Methodology

The objective of this literature survey is to identify and analyze how socially assistive robots are being used to address critical health and wellness-related issues brought upon by the COVID-19 pandemic for older adults and their caregivers. We conducted a mixed systematic-integrative review approach. Namely, the specific research questions we addressed were: (1) what are the impacts of the pandemic on the needs of older adults and their caregivers, (2) which SARs were deployed during the pandemic for this vulnerable demographic, (3) what type of help and tasks did the robots provide older adults and their caregivers, and (4) what were the enablers and barriers to the usage and adoption of SARs during the pandemic?

For the first stage of our review, a systematic search was completed using a meta-search engine, which used such scientific databases as Scopus, PubMed, and IEEE Xplore. A Google search of print media and industry broadcast publications was also completed, all between March 2020 and June 2021, along with a search on open access archives such as ArXiv, Research Gate, and Semantic Scholar. Key words used to search the databases included: elderly, older adult, seniors, socially assistive robot, pandemic, post-pandemic, COVID-19, assistance, health, and well-being. Over 150 scholarly and media articles were identified and reviewed according to our research questions.

In the second stage, a list of articles was selected utilizing the following inclusion criteria: (1) the robots had to be socially assistive robots, (2) the robots had to be helping older adults and their caregivers, and (3) the timeframe had to be during the pandemic (March 2020 through June 2021). We used these criteria to build a table of 7 commercially available SARs used during the pandemic to help older adults and their caregivers (Section 4.1, Table 1). As our focus is on robots providing assistance through social means, we excluded robots without any interactive or social human interaction capabilities. The results of our findings were synthesized to identify and discuss enablers and barriers to the technology, as well as to identify emerging future research trends.

3. Crisis in Long-Term Care Homes/Hospitals

In this section, we investigate Research Question 1: What are the impacts of the pandemic on the needs of older adults and their caregivers? Namely, we explore the crisis that the COVID-19 pandemic has brought about in long-term care homes and hospitals.

For example, the proportion of COVID-19 deaths in long-term care and retirement residences alone represents 69% of Canada's overall COVID-19 deaths, significantly higher than the international average of 41% [13]. In the US, more than 40% of the documented deaths due to COVID-19 have been nursing home residents [17,18]. Over 50% of all nursing homes in the U.S. were already hit by COVID-19 by winter 2020, with about one in five nursing home residents with COVID-19 dying from the illness [19]. Some European countries such as France and Ireland have reported that 50% of the deaths have been residents of nursing homes [20,21].

Institutional care suffers from regulatory neglect, low staff to resident ratios, as well as low wages for front-line staff, high turnover rate among employees, and part-time employees who work in multiple homes and get no paid sick leave. All of these factors contribute to creating environments with minimal resilience to adverse events. Evidence on how this crisis can be addressed includes relationship-centered solutions, integrated health and social care, and telehealth [20,21]. SARs, being resilient to future outbreaks, and providing ways for residents of long-term care homes to keep in contact with healthcare providers and family members, can be part of the solution. In a study conducted in nursing homes in Japan, it was found that the adoption of robots decreased difficulty in staff retention, and that robots can be used to meet the challenges imposed by a rapidly aging population [22].

In Japan, about 60% of nursing homes currently use SARs, including during the COVID-19 pandemic, and of the nursing homes that adopted robots, there were 8–11% more staff than at nursing homes that did not adopt robots [23]. The robot type that has the highest rate of adoption is a monitoring robot that is used to alert nurses or caregivers if there is any abnormal activity, especially during the night when there are fewer staff available. This is a real example of robots not replacing care workers, but supplementing them, allowing for critical personnel to focus more on patient care, and thereby increasing the quality of care [23].

Older adults have also increased their use of technology, such as making video calls to stay in touch with family and friends during the pandemic [24]. Expanding tech literacy is a new skill that will likely stay with the elderly after lockdowns have been lifted [25].

People with Dementia Coping with COVID-19

Social distancing and self-isolation are disrupting routine and regular support systems for the elderly. This is particularly concerning for residents with dementia, since strategies normally used to manage dementia symptoms, such as distraction, stimulation, and social interaction, have been limited [26]. Dementia can worsen under stress, especially with changes to daily routines [27].

A telephone survey conducted during the first month of the lockdown in April 2020 with 139 participants attending the Center for Cognitive Disturbances and Dementia, at Sapienza University of Rome (Italy), who were either living with mild cognitive deficits or were caregivers of people with dementia, found that one third of those surveyed had worsening cognitive symptoms (memory and orientation abilities) as well as a reduced level of independence in personal care and housekeeping [26]. More than half of the respondents experienced agitation/aggression, apathy, and depression. It is particularly worth noting that half of the caregivers reported higher levels of stress and exhaustion. It was concluded that alternative forms of support, such as technological support, are urgently needed [26].

In a study conducted in Korea between September 2018 and February 2020, just before the onset of the pandemic, 24 participants with mild cognitive impairment used the robot Bomy, a small personal care robot equipped with cognitive training games, in their homes for four weeks [28]. The robot encouraged participation in scheduled cognitive training programs, and alerted designated caregivers if participation was lacking. It was found that working memory improved when people with mild cognitive impairment used the personal care robot in their homes for cognitive intervention [28]. The robot seal Paro has also been shown to help reduce stress and minimize feelings of isolation and despair among people with dementia [29,30]. In general, SARs have shown promise in helping people with dementia by providing companionship [31], cognitive and social stimulation [32,33], and assistance with activities of daily living [34]. SARs hold specific promise to mitigate the impacts of COVID-19 by providing this population with complementary support to alleviate anxiety, irritability and agitation, loneliness and isolation, while improving engagement and reducing caregiver burden [31].

4. How Are Socially Assistive Robots Helping during COVID-19?

Robotic technology is one of the best resources for battling COVID-19 [35]. Robots are being used to move people out of high-risk situations, including: (1) to disinfect hospitals and urban streets, as mobile UV or spraying robots [36], (2) to prepare orders, stock shelves and fulfill orders at retail stores, warehouses, and perform inventory checks [37], and (3) the delivery of groceries, food, and other products [38,39]. For example, robots are also being used for meal delivery to those in quarantine, including monitoring to check that people are following quarantine enforcement [40], advising people to maintain social distancing [41], and autonomously delivering supplies, such as water or medication to dedicated spots in hospital rooms, or by delivering blood samples to the lab for analysis [42].

Robots can be equipped with infrared (IR) sensors or non-contact thermometers to evaluate temperature in a contactless way [43], and RGB cameras to measure breathing rate, pulse rate, and blood oxygen saturation [44]. Some hospitals are operating with fewer staff numbers to try to minimize the exposure of their workforce to the virus; therefore, it is essential for staff to focus their time on patient/resident care rather than on repetitive tasks, such as enforcing face mask and social distancing rules, and spraying disinfectant [45]. SARs can perform these repetitive tasks and reduce unnecessary contact between healthcare workers and residents in long-term care to keep vulnerable older adults safe.

In a worldwide study that looked at SAR implementation at large in society during the pandemic (between March–June 2020), three main roles were identified for these types of robots: (1) a liaison in tasks that require human–human interaction such as monitoring and social interaction, (2) a safeguard, implementing protective measures against the virus, to ensure a contagion risk-free environment, and (3) a well-being coach, which includes providing entertainment for quarantined patients and residents, medical and well-being adherence, and the promotion of physical exercise [46]. Robot functions associated with the roles of liaison and safeguard are now more visible due to the pandemic: SARs acting as safeguards help to enforce COVID-19 protective measures by detecting and ensuring that people are wearing masks or maintaining the required physical distances. They have also been equipped with technologies for surface disinfection. This study highlights the increase in the relevance of the liaison and safeguard robot functions due to the pandemic's demands of physical distancing and isolation. However, there is a need for well-being robot coaches to provide more effective psychological aid to people in isolation during the pandemic [46]. These robots can, for example, initiate conversations to address concerns about the virus when the older person is feeling anxious, since these types of functions have rarely been specifically adapted for a pandemic situation.

4.1. Socially Assistive Robots Used during COVID-19

In this section, we investigate Research Question 2: Which SARs were deployed during the pandemic for this vulnerable demographic? Herein, we discuss commercially available SARs used during the COVID-19 pandemic with older adults. A major limitation during the pandemic was that few research robots (or robots under development) were able to be deployed in long-term care homes, due to lockdowns and restrictions. We, therefore, focused our survey on commercially available SARs. In the future, we anticipate seeing more HRI research as facilities open up again. Furthermore, in this section, we investigate Research Question 3: What type of help and tasks did the robots provide older adults and their caregivers? We identify the specific applications of SARs during the pandemic to help the older population and their caregivers. A summary of the commercially available robots, along with their main functions during the pandemic, is provided in Table 1. The robots all have multimodal communication abilities, and were able to perform multiple functions, including: (1) health monitoring (routinely checking vital signs and alerting healthcare professionals of any abnormalities), (2) screening of visitors (checking for masks and measuring temperature upon entering facilities), (3) social facilitation (enabling video communication between residents and families or healthcare staff), (4) activity facilitation (singing, dancing), (5) providing information and reminders for tasks (weather and food menu, scheduled activities), and (6) cognitive and physical training activities (memory games, exercises). The main features and benefits of each robot are discussed in more detail below. Barriers and technical improvements are synthesized and discussed in Sections 6.2 and 7.2, respectively.

Table 1. Summary of surveyed commercial socially assistive robots (SARs) deployed during the COVID-19 pandemic with older adults.

Robot Name, Company/Developer	Main Features	Environment/Location	Function during the COVID-19 Pandemic	Reference
Pepper, by Softbank Robotics  Reprinted with permission from ASBLab, University of Toronto. 2021	1.2 m-tall mobile humanoid robot with two arms, a head, and a torso with a touchscreen tablet Facial and mask recognition, natural language processing	Deployed in hospitals, elderly care homes. Japan, France, Britain	Health monitoring Screening Activity facilitation Providing information Cognitive and physical training	[47,48]

Table 1. *Cont.*

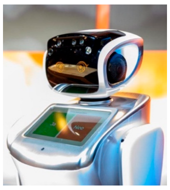
Robot Name, Company/Developer	Main Features	Environment/Location	Function during the COVID-19 Pandemic	Reference
Temi, by Robotemi  Reprinted with permission from Robotemi. 2021	1 m-tall mobile robot, with a touchscreen tablet for a head Facial recognition, natural language processing	Deployed in hospitals, elderly care homes. Israel, Germany, United States, China, South Korea, Hong Kong	Health monitoring Screening Social facilitation	[49,50]
Sanbot Elf, by Qihan Technology  Reprinted with permission from SARA Robotics. 2021	1 m-tall mobile robot with two arms, a head, and a torso with a touchscreen tablet Facial and speech recognition	Deployed in elderly care homes and hospitals. Netherlands, Italy	Health monitoring Social facilitation Activity facilitation Providing information, and reminding of tasks	[51]
Lio, by F&P Robotics  Reprinted with permission from F&P Robotics. 2021	1 m-tall mobile robot with a non-touch display on its base, and one 6-degree-of-freedom (DoF) robotic arm Facial and speech recognition, Object manipulation	Deployed in elderly care homes and hospitals. Switzerland, Germany	Health monitoring Activity facilitation Providing information, and reminding of tasks Physical training	[52,53]
James, by Zorabots  Reprinted with permission from Zorabots. 2021	1.2 m-tall mobile robot with a touchscreen tablet for a head Facial and speech recognition Tele-operation features Multi-robot coordination	Deployed in elderly care homes. Belgium	Health monitoring Social facilitation	[54,55]

Table 1. *Cont.*

Robot Name, Company/Developer	Main Features	Environment/Location	Function during the COVID-19 Pandemic	Reference
ARI, by PAL Robotics  Reprinted with permission from PAL Robotics. 2021	1.65 m mobile humanoid robot with two arms, a head, and a torso with a touchscreen tablet Facial recognition, natural language processing Connects to other smart devices	Deployed in elderly care homes. Spain, Italy, Greece, Ireland	Health monitoring Screening Activity facilitation Social facilitation Providing information, and reminding of tasks Cognitive and physical training	[56,57]
Misty, by Misty Robotics  Reprinted with permission from Misty Robotics. 2021	36 cm mobile robot with 2 arms Facial and speech recognition	Deployed in homes of the elderly. United States, Spain	Health monitoring Screening Activity facilitation Providing information and reminding of tasks	[58,59]

Pepper, by Softbank Robotics, is a 1.2 m-tall mobile humanoid robot with two arms, a head, and a torso with a touchscreen tablet [48]. Pepper is expressive through gestures and voice, and is able to communicate using natural language processing. Pepper's main strengths are that it uses an open source deep learning mask detection software, adapted from AIZoo Tech's FaceMaskDetection, to first detect people's faces and then determine if they are wearing masks [60]. It can verbally ask questions from a COVID-19 screening questionnaire, and give directives, such as to sanitize hands and maintain social distancing, which is useful in elderly care homes, where they have to routinely screen visitors and care staff [47]. Finding ways to keep the elderly safe in hospitals and care homes has become a priority during the pandemic. Since Pepper is mobile and people can communicate with it verbally, rather than using its touchscreen tablet, this helps to reduce the risk of viral infection [47]. The tablet can be used for providing information and instructions to individuals. Pepper can also perform cognitive and physical training activities [47].

Temi (short for "technology for me"), by Robotemi, is a 1 m-tall mobile robot, with a touchscreen tablet for a head [50]. Temi communicates through conversational assistance via Amazon Alexa or its own technology, which includes natural language processing, and speech-to-text/text-to-speech engines. It also has facial recognition capabilities [50,61]. Initially designed as a companion to seniors living in their own homes, it has now been deployed to help with COVID-19 outbreaks in elderly care homes [49] to help minimize human-to-human contact. The robot's main benefits are that it can perform health monitoring and screening and has been outfitted with an IR camera for temperature taking, and a tray that can carry hand sanitizers [50,61]. Furthermore, Temi will also be equipped in the future to be able to detect heart rate, heart rate variability, respiratory rate, respiratory and heart rate waveforms using a 4D intelligent RF sensor developed by Vayyar Imaging. Then, in real time, the vital signs and COVID-19 infection risk level of a person will be determined and presented on the robot's screen [62]. Temi can conduct telepresence sessions through an integrated app, allowing residents in care homes to maintain their social networks during lockdowns and when limited visitors are allowed. In April 2020, Connected Living, a social impact company that serves senior living communities worldwide by providing technology solutions to create connected communities for seniors, partnered with Robotemi for the deployment of the robot. They are deploying the robots in Maplewood Senior Living, in the United States, to act as a companion and improve the well-being of the residents through social facilitation, such as by providing telehealth calls to residents or connecting remotely with family members, and to help stop the spread of COVID-19, by bringing hand sanitizer, asking residents to wash their hands, and taking temperature readings from visitors [63].

Sanbot Elf, by Qihan Technology, is a 1 m-tall mobile robot with two arms, a head, and a torso with a touchscreen tablet [64]. The robot has facial and speech recognition capabilities. The main benefits of this robot are that it can host a medical service platform developed by SARA Robotics that can cooperate with the medical care platforms of hospitals, and elderly care homes [65]. SARA Robotics has deployed this robot in twelve care facilities and hospitals in the Netherlands to improve quality of life and provide support to alleviate caregiver staffing shortages [51]. The robot acts as a support to elderly people suffering from dementia by providing cognitive and physical exercises, games, music therapy, and performing repetitive tasks, such as reminding staff and residents of upcoming events [51]. SARA Robotics is planning to expand the functionalities of the robot, introducing autonomous navigation and home automation, where the robot will be able to detect falls using its cameras [66]. The SARA Home system allows caregivers to provide a personalized profile and health plan for every client. SARA Robotics is continuing to gather feedback from care facilities as to how to alleviate the work burden on health care professionals, and how to improve quality of life for residents. At the beginning of the pandemic, six Sanbot Elf robots were deployed in the Circolo Hospital in Varese, Italy, a region at the epicenter of the COVID-19 outbreak [67], where the robots helped to keep patients connected to healthcare staff through its video chat capabilities.

Lio, by F&P Robotics, is a 1 m-tall mobile robot with a non-touch display on its base and one six-degrees-of-freedom (DoF) robotic arm with manipulation capabilities [53]. Lio's main strengths are that it also has a multifunctional robotic arm with a gripper that can pick up small objects, such as water bottles, and transport them on its platform; the arm can also be used for disinfecting tasks [53]. It also has facial and speech recognition capabilities. During the COVID-19 pandemic, Lio has been adapted to perform disinfection tasks by grasping a UV-C light that it carries and placing it over the object to be disinfected. Lio can perform health monitoring by detecting people with an elevated body temperature using its IR camera placed on its gripper [52]. If an elevated temperature is detected, the robot alerts medical personnel. Lio has four embedded processing units, so data can be stored locally on the robot, without the need for cloud computing, to ensure data privacy. The robot can also perform physical activity facilitation, provide information and reminders of tasks [52,53].

James, by Zorabots, is a 1.2 m-tall mobile robot with a touchscreen tablet for a head [55]. James has facial and speech recognition capabilities. The robot is being used in elderly care homes in Belgium during the COVID-19 pandemic to help residents keep in contact with family and loved ones through video calls on its tablet [54,68]. Its main strengths are that it incorporates the Zora software application that can be used to control and coordinate multiple James robots; it also lets a user tele-operate the robot via local network or cloud connection [69]. The James robot is part of ReMember-Me, a smart system deployed across countries in Europe and Latin America which aids in the prevention and detection of cognitive decline among older adults [70]. The robot monitors a person's health status, and engages the elderly in personalized cognitive activities, as well as promotes social inclusion among older adults [70]. The system includes sleep, activity, and mood assessment, short daily exercises, and socialization [70].

ARI, by Pal Robotics, is a 1.65 m-tall mobile humanoid robot with two arms, a head, and a torso with a touchscreen tablet [57]. ARI is able to communicate via natural language processing, and has object and face recognition [57]. Its main benefits are that it can display multimodal behavior through gaze direction, speech, and gestures to directly interact with people in bi-directional communication. ARI can also connect with other smart devices, wearable sensors, and applications to monitor the health and well-being of older adults [56]. Due to the pandemic, ARI has been modified to include an IR camera in its head to detect temperature. In spring and summer of 2021, ARI will be taking part in several pilot projects with older people living in their own homes, or in residential care homes, in Spain, Italy, Greece, and Ireland. Pilot 1 consisted of four to five participants between 70 and 80 years old over a four week period, at Clinica Humana in Mallorca, Spain in May 2021 [71,72]. ARI was deployed to detect temperature, provide reminders, entertain and connect to others through video calls. The next pilot will be in residential homes, where ARI will act as a companion robot, and with the help of a psychologist, will be used as a complementary tool to promote engagement in cognitive games such as Tic-Tac-Toe [71,72].

Misty, by Misty Robotics, is a 36 cm-tall mobile robot with two arms [59]. Misty has facial and speech recognition capabilities. During the pandemic, the robot has been integrated with an IR camera in its visor, and can be equipped with UV lamps for disinfection [73]. In addition to non-contact temperature sensing, the robot can ask health screening questions [58]. The results are recorded and available through an admin portal, and texted or emailed to designated care personnel, which is an asset of this robot [58]. In Spain, Misty is being used to augment the abilities of human care providers whose job it was to visit those aging-in-place in their own homes, by allowing them to remotely check in more frequently than what is possible with home visits, even with pandemic quarantining regulations. Misty keeps track of the health of the elderly through asking them questions about daily habits such as sleep quality, medication taking, and diet [74]. Another of its strengths is that Misty also helps address loneliness in the elderly by providing companionship through dancing, telling jokes, and playing music.

5. How Has Perception about Robots Shifted Due to the Pandemic?

The use of robots was already on the rise before the pandemic [75,76]. According to the International Federation of Robotics report, worldwide sales of professional service robots jumped by 32% to USD 11.2 billion between 2018 and 2019. The number of service robots (for personal and domestic use) increased by 34% to more than 23.2 million units sold in 2019 (at a value of USD 5.7 billion) [77].

The unprecedented impact of COVID-19 on health and global economies has resulted in a renewed interest in AI and robotics to mitigate its effect [78]. Intelligent automation (IA), defined as "the application of AI in ways that can learn, adapt and improve over time to automate tasks that were formally undertaken by a human" [79], has seen increased adoption following the onset of the COVID-19 pandemic. One of the main reasons for this is that consumer preferences are starting to change; as human contact has become risky, people are starting to see these technologies as helping to protect their health [78]. People are also becoming more familiar with using different technologies, such as video conferencing tools, and personal needs and motivations in turn influence social practice, creating a favourable, receptive environment for the adoption of IA [78]. Business confidence in IA is also seen as being on the rise, due to rapid changes triggered by COVID-19 [78].

Organizations are being steered toward a digital transformation sooner than planned due to the pandemic, which has sped up the increase in the number of ways in which robots are being used to limit the spread of the virus [35]. SARs are being used during the COVID-19 pandemic in elderly care homes, where residents are in need of companionship. This was observed in Japan [23,80], France [47], the Netherlands [51], Belgium [54,68], Britain [81], and the United States [63,82], among others.

Overall, users' perceived sense of the usefulness of SARs and the acceptance of their use have increased due to the pandemic [4]. An online questionnaire developed by the

University of Waterloo in Canada measured aspects of people's experience of COVID-19, such as feelings of loneliness and stress, and their attitudes and acceptance of SARs as companions [83]. The questionnaire was answered by 102 people in Canada. The results show that a change in lifestyle as a result of the pandemic led to a change in the perception of benefits of companion robots. In the absence of human contact, people viewed a SAR as a potential companion to reduce social isolation. The study found that people preferred a robot 'to not require any maintenance', and that they valued human characteristics in SARs, such as the ability to show emotions and recognize users, as much more important than technical accuracy [83].

6. Enablers and Barriers

In this section, we address Research Question 4: What were the enablers and barriers to the usage and adoption of SARs during the pandemic? We investigate both the enablers and barriers to effectively incorporating SARs in healthcare and social care settings during a pandemic and in a post-pandemic world.

SARs can be used to respond to the challenges of an aging population and labour shortages of caregivers, and to mitigate the effects of social isolation and loneliness [6]. In long-term care facilities, providing older adults with technology, such as smartphones, tablets, VR headsets, or access to SARs, could decrease their sense of loneliness and increase their self-perceived health through doing independent activities [84]. In fact, a study conducted in nursing homes and geriatric hospitals in Germany during the pandemic in 2020 found that the physical presence and appearance of the Temi robot were received more positively by residents, when compared to a tablet, when both were used for video chats [85].

The following subsection will outline the enablers to implementing SARs, followed by some of the main barriers and how to address them, with the aim being to guide future research directions based on the uptake and use of SARs during pandemic situations and as well post-pandemic.

6.1. Enablers

The main enablers to the implementation of SARs for older adults in health and social care have been adapted from [86] to directly focus on the pandemic: (1) a general positive HRI experience with the robot, and an overall enjoyment of activities engaged in with the robot, (2) personalization, such as the adaptation to users' preferences, care needs, and impairments, (3) usability of the robot, and (4) comfort with the robot and familiarization. In addition to these four categories, COVID-19 has highlighted additional enablers: (5) community support behind using robots, and (6) promotion of independence and autonomy.

6.1.1. Positive HRI Experience

During the pandemic, human-to-human social contact was limited or restricted. For the successful implementation and acceptance of SARs, a positive HRI experience is important. This can be achieved by having robots perceive and respond directly to older adults' affect during interactions [87]. The robot should also be kind, friendly, and provide comfort and motivation [86].

It should be able to mitigate the effects of social isolation by keeping residents socially and physically engaged, through leisure activities, cognitive interventions, or through physical exercises [88]. In one study exploring the impact of SARs on the health and well-being of older adults in social care settings in England and Japan pre-COVID, the Pepper robot interacted in a culturally competent way with residents; it was aware of the participant's cultural background, and tailored its interactions accordingly (for example, a wave instead of a bow; playing English music and movies instead of Japanese) [89]. The results show that (1) older adults who interacted with the robot demonstrated a significant improvement in their mental health; (2) after two weeks, there was a small but positive impact on loneliness severity among users; and (3) there was a significant positive impact on people's attitudes towards the robot [89,90].

6.1.2. Personalization

Personalization is particularly important when SARs are shared among residents in a facility. Implementation and contactless interaction during the pandemic will be more successful if the robot recognizes and adapts to the specific needs of the user. Personalization, which can include volume and speed control for the robot's voice, text size presented on displays, and the level of difficulty of an activity, can be especially important when there are multiple users for each robot [91].

Older adults are not a homogeneous group and have different daily living needs. For this reason, personalizable functions in a SAR are essential for promoting independent living in older adults. This type of robot can be especially useful for people with cognitive decline who rely on reminders. In fact, pre-COVID, in one study with older adults living in their own homes using the daily care robot Bomy, by Robocare, participants valued the personalized medication and health-related reminders the robot gave the most [92]. In another study, the Pepper robot provided more personalized interactions when it was aware of participants' individual cultural preferences [89].

Personalizing a robot according to the needs of people living with dementia, such as providing daily medication or health appointment reminders, can also positively improve carers' views on the robot [93]. This is known as person-centered care and it involves providing assistance that is adapted to the user's physical, psychological, and social needs as well as their overall personality. For example, the robot's behaviors can be tailored to the level of cognition of the user, which over time can change. What can be effective is that the robot can learn these behaviors directly from caregivers who are providing assistance and who understand the needs of the older adults [34]. This can be done using learning from demonstration and reinforcement learning techniques, as shown in our previous work [34]. HRI studies have also found that adapting a robot to a user's needs can directly improve their overall attitudes towards the robot [94].

In long-term care environments, where residents may have cognitive impairments, a robot's capacity for social intelligence is important; if the robot can determine the user's intent as well as affect, it can adapt its assistive behavior for each user during HRI, thereby promoting more engaging HRIs [87].

6.1.3. Usability

The usability of the robot, which includes intuitiveness with respect to interaction and ease of use, is crucial, especially during the COVID-19 pandemic, when risk of infection is high. Caregivers and staff may not be available to help residents every time they want to interact with the robot. In a study with people with dementia, it was reported that they felt unhappy about always asking for help, so the opportunity/ability to select the activities they wanted to do with the SAR on their own was highly valued [93]. The workload of nursing staff and caregivers is reduced if the robot is autonomous, especially if it can autonomously navigate into quarantined rooms and interact with residents [85].

In general, older adults may have been unfamiliar or not as comfortable using the latest technology, but the COVID-19 pandemic has highlighted this predicament and has actually shown an increased use of technology among this group during the pandemic [95,96]. Research has shown that for older adults, learning to use and engage with diverse social technology offers benefits through direct cognitive stimulation, since different cognitive functions, including memory, recall and decision making are required [97].

One way to improve attitudes towards robots is through direct experience [98], such as through user sessions with a SAR in which the older adults are introduced to the robot, its functionality is explained, and they are able to experience interacting with it; this direct experience over time will help to reduce the generational digital divide [98,99]. However, it was found that acceptance of SARs in the longer term, including during COVID-19, remains to be clarified [100].

6.1.4. Comfort and Familiarization

Comfort and familiarization with SARs depend on the amount of time spent interacting with it—this has likely increased during the pandemic, due to restricted human-to-human contact—and if the SAR is present and available in a facility. It is worth noting that individuals who had not previously interacted with SARs started to during the pandemic due to a need or want. Pet-like robots such as the seal-like PARO [101,102] and Joy for All Companion Pets (robotic cats and dogs) [103] were very popular with older adults during the pandemic; even those who did not want to initially use the technology ended up enjoying their interactions, as the robots improved moods and decreased loneliness [82,102,104]. The successful interaction between robots and humans will vary depending on the context and the user; for example, a caregiver or staff member might find it beneficial and necessary to fully familiarize themselves with a SAR's system and to understand system capabilities, so they can modify them as needed for the different residents in their care, whereas a person living with dementia might be overloaded with too much information that is not relevant to them, and would benefit from a simple, straightforward interaction with the SAR. It is also important for the user to understand the intent and purpose of the robot [105], so as to increase their level of comfort. For example, when robots were deployed in Italy to help with the pandemic response in a hospital, older patients' initial reactions were one of animosity towards the robots; they wanted to be looked after by a human [67]. However, after explaining the aim and function of the robot, it was understood that doctors and nurses were also getting infected, and there was not enough personal protective equipment (PPE), so patients accepted the robot as a tool to help protect the health of the healthcare workers, and through which they could remotely interact with doctors and family [67].

6.1.5. Community Support

If there is support from family and caregivers for older adults to use SARs, older adults' acceptance of the technology will increase [93]. Identity and self-image play an important role in influencing older adults when it comes to the use of assistive technologies, leading them to reject these technologies, which can be perceived as stigmatizing and ageist [106]. Using an assistive technology can indicate weakness and frailty—many older adults agree in theory that a SAR could be helpful, but were quick to point out that it was for people worse off than them, or something they could use in the future [93]. On the flip side, the use of robots may make older adults feel more connected to society, since they are participating in the digital era and using what is perceived by others to be a "technology of the future" [107]. Due to the COVID-19 pandemic's social distancing regulations, older adults can directly benefit from using SARs, since it prevents infection from direct contact with other people, while still maintaining social communication and engagement.

6.1.6. Independence and Autonomy

SARs can be used to promote independence and aging-at-home by supporting older adults' needs while helping them with activities of daily living, such as preparing and eating meals, dressing, personal hygiene tasks, etc. [34,108]. In long-term care facilities, older adults can still enjoy some degree of autonomy by choosing their own daily schedules, provided by a robot, from within available options [107]. User studies with people with dementia have shown that SARs improve social engagement through facilitating conversations, and increase the older adult's level of independence and autonomy by giving reminders or offering them choices of activities [93,102,107].

6.2. Barriers

The main barriers to the implementation of SARs for older adults are: (1) technical limitations, from both a software and hardware perspective, (2) a lack of training of staff and caregivers on how to use the robot, (3) ethical and privacy concerns, and (4) design.

6.2.1. Technical Limitations

Existing technical limitations can include: (1) speech recognition analysis (the robot does not recognize what the human is saying, or conversely, the human does not understand the instructions of the robot), (2) navigation (the robot is unable to autonomously navigate the environments with people due to crowded hallways, obstacles, stairs, uneven terrain, etc.), and (3) touchscreen sensitivity issues (there is a delay in input via the touchscreen). For these limitations to currently be overcome in a real-world setting, some form of human control is required via a moderator that interprets information for the user, or by Wizard-of Oz from a tele-operator controlling the robot's behaviors and motions [109]. During the COVID-19 pandemic, robots have helped to minimize person-to-person contact, so the autonomy of the robot is important; the need for human intervention should be minimized as much as possible. The accuracy of voice recognition software is crucial and an open research area; however, challenges exist with interferences from background noise, and age-related degeneration of speech [93,110]. This results in users being forced to interact with SARs via touchscreens [98], which introduces sanitization issues. Many robots also need help to fully navigate autonomously; either through the placement of navigation markers in the environment [52], or by having a moderator physically move the robot to where it needs to be, so a user can better see or read what is displayed on the tablet [109].

It would be beneficial for SARs to function in teams or groups as a secure, complete network of robots; the sharing of information across such a smart network can be more effective in fighting this pandemic, as well as future ones, within our society [111]. This poses a challenge from a technical point of view due to the heterogeneity of the SARs currently deployed. This would require a uniform software platform across which the robots could be connected and able to share information and user data, with heightened security and privacy measures.

Technical limitations can impact the usability of the technology, and ease of use is particularly essential for older adults when it comes to the acceptance of technology, since they may have had limited exposure to such robots. Due to the issues around navigation and speech recognition, which still require improvement [99], as well as the heterogeneity of SARs, having fully autonomous robots so as to minimize human–human contact may currently not always be possible depending on the interaction scenarios and environments.

6.2.2. Lack of Training

We must consider that in long-term care facilities, staff and caregivers are also using the technology, alongside the residents. In Europe, the Intercultural Education of Nurses in Europe (IENE-10) program is trying to fill the gap caused by the absence of training courses on SARs and AI in health and social care. They are producing training materials for health and social care professionals, as well as a massive open access online course (MOOC) that focuses on the theme of transcultural robotic nursing, a term coined by the caressesrobot.org project [112], with the goal of raising awareness of the potential advantages, negative and positive implications and the ethics of using AI and SARs in health and social care [113].

While the majority of research has been focused on the acceptance of SARs by older adult users, it is important to not overlook the needs of healthcare workers, which should be further investigated [86]. In a healthcare facility, the training of staff is also needed on how to use the robots, so healthcare workers can quickly and effectively engage the robot to perform tasks, as well as in giving guidance to others on how to interact with the robots [107]. Education on using the SARs may be perceived as additional workload for caregivers and staff at first; however, the robots can provide task support for caregivers and help when their workload is large to minimize work-related stress [114]. This was especially needed during the COVID-19 pandemic when care staff were overloaded with tasks.

6.2.3. Privacy and Ethics

As a large number of SARs are also mobile and can access private rooms of residents in long-term care homes, concerns around safety and privacy in a healthcare context are of particular importance. Three types of privacy concerns have been identified [115]: (1) institutional informational privacy risks: how much information does the robot manufacturer have access to? Is the robot transmitting user data to for-profit companies? Can targeted marketing occur through the robot?; (2) social informational privacy risks: since robots can record voices, images and videos of users, and store user data, if these data are kept in the cloud, can sensitive user information be accessed or hacked by others?; and (3) physical privacy: when entering private rooms, how much recording of personal activities is occurring? During any scenario including the pandemic, health information is recorded by the robot; do residents know how much information is being recorded, how long it is kept, and who can access it? Especially if they contain details such as which people have COVID-19.

Social informational privacy concerns (as opposed to physical privacy) center around a user's ability to understand how information shared with the robot is stored and disseminated. These privacy concerns relate to the interaction between a user and a robot, and also to the interactions between individuals through a robot, particularly if surveillance takes place, unbeknownst to the user, through a telepresence robot [116].

One way to address privacy concerns is to use tools for encryption and anonymizing data [6]. Another way is to store user information locally on the robot.

Hybrid ownership must also be taken into account: the robot does not belong solely to the user (the elderly person), but also to the manufacturer (who has remote access to it for when it requires upgrades), the healthcare facility that purchased it, or family members of the elderly. Context analysis is needed to shape regulatory protections based on the different kinds of social situations in which the robot is used [6].

There is the perception that deploying robots in long-term care facilities might also signal societal abandonment of older adults, or even counterfeit companionship [6]. The concern with SARs is that their use may deceive users, as they feign human mental and emotional capabilities [117]. Eye contact, human-like gestures, and the conversational ability of the robot lead to the illusion of understanding [118]. Another concern is that an imaginary relationship with a robot is ethically wrong, and should not be encouraged [119]. We must carefully examine potential outcomes when designing these robots. The entire field of roboethics is dedicated to this. The field started in the 2000s and has aimed to define regulations and standards around the design and use of robots. The main topics covered are [120] (1) the use and storage of data as discussed above, (2) the design of robots for the common good and betterment of humanity, and (3) the safety of both the user and robot.

The alternative to robot companionship for many older people during the pandemic is social isolation and loneliness. In these circumstances, robots do not rob these individuals of human companionship, but rather afford companionship where it is lacking, while maintaining social distancing rules. Human–robot relationships can be a lifeline during a pandemic [6], by (1) safeguarding the health and well-being of socially isolated older adults, (2) providing a means to remotely connect with medical professionals or to loved ones, and (3) providing a socially engaging environment to ward off loneliness, with leisure and stimulating activities such as singing, dancing, and playing games. As they are interactive, SARs can convey to users that they are being perceived, heard, understood and attended to [121].

6.2.4. Design

Additional barriers include technology that was not designed purposely for the elderly. Using lessons learned when designing user interfaces, these same lessons can be applied to robots. Personalizing a robot for elderly users through design can include bigger icons and shapes/buttons, and large display fonts on the tablets, along with volume control for the hearing impaired [122]. Multimodal inputs, such as speech, touchscreen, or gestures, are ideal since they enable interactions with users with varying abilities [123,124]. However, during the pandemic, in order to minimize the transmission of infection, contactless communication is preferable, highlighting the importance of voice commands, speech and gesture recognition in SARs used with older adults [93], as well as the robot's ability to adapt its own behavior by detecting the intent and affect of users [87]. The use of touchscreens as the input for commands to the robot [92,93] requires human intervention to disinfect the screens after each person uses the device, which can add additional work for staff already overloaded due to the pandemic. If residents have severe cognitive impairments, they may lose the ability to make use of a SAR [107]. Designing a robot to adapt and respond to the user, such as through voice commands and gestures, or through initiating interaction, is particularly useful for older adults with mild cognitive impairments, who might forget how to use the robot after a period of inactivity [92,93].

7. Robots in a Post-Pandemic World: Roadmap for Future Research Directions

Lockdowns and quarantines in elder care facilities are not new and occurred pre-pandemic, due to outbreaks of contagious viruses, such as the flu and shingles, and will continue post-pandemic. The pandemic has shown us that finding ways to keep the elderly safe in hospitals and care facilities has become a priority, as they truly are vulnerable. Extended periods of social isolation can deteriorate the psychological well-being of individuals, making at-risk populations such as the elderly particularly susceptible during the COVID-19 pandemic. To mitigate negative psychological effects while in quarantine, such as anxiety, stress, and depression, it is important to give people as much information as possible through effective and rapid communication; the ability to communicate directly with loved ones could reduce feelings of isolation, stress, and panic [11]. Public health officials need clear lines of communication with those quarantined to provide instructions as to what to do if symptoms appear and to reassure people they will be cared for if they become ill, and that they have not been forgotten [11].

There are unique interaction and engagement opportunities with SAR technology as well as the potential to maintain or improve physical and cognitive well-being of older adults during the pandemic, and post-pandemic. In this section, we provide a roadmap for the future research directions for how SARs can help the emotional well-being of older adults in a post-pandemic world, based on what we have learned during the COVID-19 pandemic. In particular, we will discuss: (1) the use of automation in healthcare facilities, (2) how to overcome barriers through technical improvements, and (3) future applications of SARs.

7.1. Automation in Health-Care Facilities

In general, long-term care homes do not have a lot of automation. They need to consider automation as a solution in their care services. There has been a re-evaluation of systems and protocols during COVID-19, and this is being transferred into a general re-evaluation of long-term automation in healthcare. With a focus on minimizing person-to-person contact, health systems can use robots to increase efficiency and enhance care by providing contact-free help, which protects residents and staff from infectious diseases, including remote patient monitoring, and home therapy robotic devices [125]. Smart automation can be used in many places in hospitals and long-term care homes, from front desks, such as by screening all visitors to a facility and reminding them of COVID-19 protocols and regulations, to outpatient environments, such as by providing social facilitation and keeping isolated older adults in contact with family members and healthcare providers, or by connecting to other sensors and devices to track the vital signs of people [125].

While social distancing directives, and the benefit to our health, is prompting the use of automation in more industries [126], successful adaptation of AI-enabled robotics can be difficult and costly, and needs to be viewed as a long-term investment [127]. These costs must be taken into account. Aside from the initial purchasing cost, many robot platforms require a monthly subscription fee; or the software could become outdated. If companies go bankrupt, people are left with a robot they may be emotionally invested in but can no longer use [120]. Universal access to assistive technologies is an ideal, but unfortunately not a reality in many regions, and there is the added cost of ongoing maintenance, disinfection, and repair [102]. Mitigating the cost could include initiatives such as government and industry grants for investment into new technologies and fiscal incentives such as tax credits [127].

7.2. Technical Improvements

In a post-pandemic world, robots are expected to be progressively more autonomous, flexible, and cooperative [128], to meet the changing healthcare needs of older adults, and provide a degree of personalization so as to facilitate cognitive and physical activities, making them more social and enjoyable for this population [129]. Challenges that will need to be addressed for all SARs, including those surveyed in Section 4.1, Table 1, are synthesized here, namely:

(1) Improving the level of autonomy; many of these robots are not yet fully autonomous in their intended environments and scenarios in order to be able to take on multiple crucial cognitive and social tasks [52,93]. Human intervention is still needed for personalization to different users, and the need for artificial landmarks for robot navigation in the environments they are to be deployed in [52,93]. In order to improve autonomy, progress is needed in a number of different but complementary research fields, such as HRI, computer vision, natural language processing specifically for older adults and those with cognitive impairments, affective computing and AI [111], and then tested and verified in the wild within these real settings with real users.
(2) Improving response time reliability for healthcare use, such as faster response times for robot deployment in critical situations and during interactions, namely the concern of network delays or too much data that could introduce delays in the robot's processing of information, decision making and outputs such as speech recognition, and tablet response [6,111].
(3) Integrating multiple sensor technologies and sensor fusion methods to extract and classify various signals to improve detection and monitoring of symptoms [130].
(4) Generating new datasets for the training of classical and deep learning methods specifically for older adults, including those living with dementia. These datasets can be used to train the intelligence of SARs, from object and person classification to learning optimal robot behaviors and actions in different scenarios.

7.3. Future Applications

Health risks due to the pandemic, such as human-to-human contact, have led to greater interest in the development of technical solutions, such as the use of SARs, to help reduce contact. With the current challenge of the global COVID-19 pandemic and the reduction in social contact, long-term care facilities can benefit from the use of SARs in assisting residents with daily care.

7.3.1. SARs for Outdoor Environments

A unique limitation with current SARs is that they are intended for indoor use. During lockdowns at long-term care facilities across the world, residents were not able to go outside for fresh air or exercise, even if they were social distancing, leaving them locked indoors for months or even a full year [131]. The potential for SARs to also be able to traverse different terrains including sidewalks to accompany older adults would be a great benefit to these individuals for both their mental and physical health. There is a need during the pandemic to provide monitoring and support to promote outdoor activities for older adults, and SARs can be designed to meet this need now and in the future [131].

7.3.2. SARs for Predicting and Monitoring Health

Other future applications of SARs include the autonomous detection and prediction of health changes in people, while monitoring vital signs and recognizing and classifying symptoms, extracting correlations, and calculating the risk of a condition worsening [80]. This can help to reduce the need for frequent visits to the hospital and help to prioritize individuals that need critical care in long-term care facilities.

7.3.3. SARs to Help with Mental Health

Since SARs can also provide improved psychological aid functions; specifically in the context of the pandemic, they can be used to suggest and facilitate care strategies, provided by health experts, targeted for older adults that are coping with stress and anxiety due to the pandemic. They could, thus, help to identify early signs of depression, cognitive decline, and dementia [132]. This will require SARs to perceive user emotions and behaviors over time, to personalize intervention, and connect these individuals to healthcare professionals when needed [133]. As previously mentioned, future robot designs will need to include robust capacities to communicate with and recognize the speech of people with dementia [93] or people with other speech impairments.

7.3.4. Technologies for SARs

SARs equipped with IR camera systems to screen for fevers and track vital sign abnormalities in a contactless way can help in treating future pandemics. Similar consumer-level systems using RGB and IR cameras have been used to extract heart rate, blood pressure, and skin temperature oxygen saturation, by detecting changes in the surface of the skin [130]. The sensors required to perform this type of health screening are not new, but the pandemic has provided an opportunity to integrate these sensors into one combined sensory system for potential robotic deployment. For example, it was integrated with Spot the robot dog, from Boston Dynamics, and used for hospital triage at the beginning of the pandemic in the United States [44]. The robotic system still needs U.S. Food and Drug Administration approval before being used in regular non-pandemic care, and not as an experimental platform deployed during COVID-19 [134]. It is still too costly for regular, everyday use (greater than USD 74,500) [134].

The COVID-19 pandemic has resulted in a massive potential growth in automation, especially in robotics [126,135]. Robots are just one part of healthcare services that can benefit from being well integrated with mobile apps, wearable physical sensors [129], other medical devices, as well as e-health records, in order to better meet the needs of our aging vulnerable population [56]. SARs are becoming multipurpose systems, and are capable of working within human teams, for example by sharing information with healthcare providers. Efficient integration of robotics and AI, along with the Internet of Things (IoT) and cloud computing, can be used in the fight against future pandemics by developing an efficient system for monitoring and detecting early signs of illness, all without human physical contact [132].

8. Conclusions

During the COVID-19 pandemic, new ways of keeping older adults socially and cognitively stimulated without direct human contact became critical to their overall well-being. Numerous changes were made to care tasks to keep both older adults and their caregivers safe, but as a result limited their access to their social networks, and increased social isolation and loneliness. The literature review presented herein provides a detailed analysis of SARs actually deployed during this time to help healthcare facilities with the main tasks of health monitoring, screening of visitors, social and activity facilitation, providing information and reminders of tasks, and cognitive and physical training, The robots show great promise in helping to reduce loneliness and improve psychological well-being, while also helping to minimize the burden on healthcare staff and caregivers. However, the pandemic has outlined a strong need for these SARs to do much more to help our vulnerable population with their mental and physical health. Technical improvements in the form of intelligence and autonomy, training, as well as societal acceptance are needed to develop and deploy this technology to have far-reaching benefits across the globe.

It is important that SARs be a "ready technology", meaning that they need to be ready to be rapidly deployed in pandemic situations; this is of critical importance in mitigating the effects of the pandemic on older adults and our society as a whole. Once the pandemic is contained, it may be that SARs will play a bigger role in our society than ever before. However, since SARs are still an emerging technology, they will require a lot of research and investment efforts in order to make them user-ready within these human-centered environments to aid older adults and their caregivers with multiple tasks autonomously. When deployed, the potential health and social impacts for older adults and their caregivers can be enormous.

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