Report on the Use of Assistive Robotics to Aid Persons with Disabilities

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Executive Summary

As technology advances in an increasingly automated and computerized world, an area of growing interest is Assistive Robotics (AR) for persons with disabilities (PWD). Assistive Robotics is divided into many subcategories such as social, task, and rehabilitation robots. The ability to automate or independently perform one or more tasks can significantly improve how PWD live and interact with others.

Although it is not possible to predict how each member of society could benefit from the integration of AR, this report focuses on a few categories of potential stakeholders and types of tasks that could be performed. The initial beneficiaries or early adopters of AR include children with disabilities, aging adults, PWD, and people undergoing rehabilitation therapy. Children with disabilities are likely to benefit from the introduction of AR into the classroom to augment learning. AR is also likely to help aging adults to remain in their homes longer rather than having to long-term care facilities if minimal medical assistance is needed. It is also foreseeable that AR could provide greater access to rehabilitation for PWD by providing in-home rehabilitation therapy.

The state-of-the-art in AR requires significant setting up and may have a steep learning curve in its usage. AR is adaptable to different users in diverse circumstances and can be programmed to accomplish specific functions in specific environments. However, these decisions have to be considered carefully and who are all the potential users. For example, social robots may be integrated into homes or other facilities and programmed to accomplish a specific set of tasks in lieu of those performed by caregivers or to assist caregivers. When approaching the design of AR for PWD, it is important to consider what potential users find most desirable in an AR system and what they find troubling or potentially dangerous. Most of all, potential users have stressed the desire for control over any AR that they interact with, and they desire the ability to customize an AR system to suit personal needs. However, the greater sophistication and autonomy an AR has the more information is needed while interacting with a user, which leads to concerns over the privacy of users' data. In multiple studies, users have described an emotional hurdle to overcome in interacting with AR. If users find the design or movements of a robot to be unsettling or "uncanny," users will stop interacting with the AR. Likewise, some users and caregivers might not perceive AR as wholly beneficial if they affect autonomy or their livelihood. Considering all these factors, the optimal design for AR varies for different user groups. What is common across all fields of AR development is that AR must be perceived as useful by the user or the AR will be quickly abandoned.

A critical feature of an AR system for those aging in place is the ability to stimulate cognitive function. By contrast, in addition to mental or physical stimulation, the most important task of rehabilitation AR is actually progress tracking. Lastly, when designing educational AR for PWD, the AR system's most important task is communication with the user. When effects of AR are examined through a larger, societal lens, it is apparent that AR will have a significant impact on several aspects of the lives of PWD, their families, friends, caretakes, and coworkers. AR is able to help PWD maintain continuous employment or allow informal caretakers to return to work, AR can help improve the personal finances of PWD. AR also has the potential to impact regional and national economies by allowing PWD, caretakers, and aging persons to remain in the workforce. AR may also alleviate caretaker stress and thereby improve health and well-being.

Chapter 1: Use of Assistive Robots for Various Stakeholders

Haley June, Kelli Stanton, Maryam Nuru, Natalie Scott, Tommy Sanders

Section 1.1: Introduction

Assistive robotics (AR) has the potential to be an important assistive aid for children with disabilities, people undergoing rehabilitation, and working age adults with disabilities and elderly adults. In this chapter, we outline why these groups would likely be major stakeholders for this promising assistive technology (AT). We then describe the particular needs of each of these stakeholders with regards to AR. We will then discuss problems being faced by each of these stakeholders and how AR can provide the needed assistance to alleviate these issues by providing specific examples of how this technology is currently being used. Lastly, we will discuss cost concerns and how each of these groups might gain access to AR by comparing the financial benefits of using AR to conventional caregiver assistance.

AT is defined as any tools, equipment, or products that assist people with disabilities (PWD) and the aging population to function independently at home, work, school, and in their communities (About Rehabilitative and Assistive Technology, 2018). AR is an emerging type of AT that has been tested for a variety of uses in homes, schools, and rehabilitation centers and come in many different forms. These different forms include task robots, socially assistive robots (SAR), or even robotic animals (Tapus, et al., 2007). Task robots, as seen below in Figure 1.1.1, were designed to autonomously perform repetitive tasks, potentially dangerous tasks, or daily tasks the user might find challenging. Task robots are often designed to be able to carefully move through the environment without disruption and can even clean or retrieve items for the user, potentially limiting the dependence on human caregivers (Wang, et al., 2003).

Figure 1.1.1: Personal Assistive Task Robot. Reprinted from Carnegie Mellon University The Robotics Institute*, 2019, Retrieved from https://www.ri.cmu.edu/research/personal-assistive-robotics/.*

SAR are designed to increase social interaction in the aging population (Lee & Riek, 2018). A literature analysis reported that the impact of loneliness often felt by the aging population carries the same mortality risk as smoking 15 cigarettes a day (Abdi, et al., 2018). The purpose of SAR are to improve the quality of life for the aging population by providing more social interaction on a daily basis. An example of a SAR can be seen below in Figure 1.1.2.

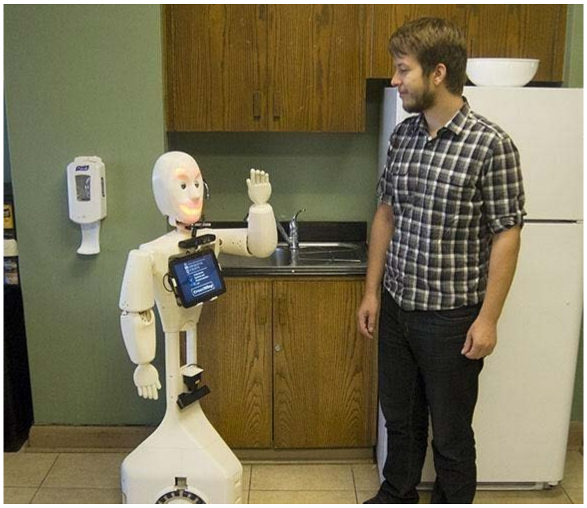

Figure 1.1.2: Casper, the Socially Assistive Robot. Adapted from Autonomous Systems and Biomechatronics Lab*, http://asblab.mie.utoronto.ca/research-areas/assistive-robotics.*

Robots with more zoomorphic or caricatured designs will likely be important in assisting children with disabilities, specifically in social settings. An example of a robotic animal can be seen in Figure 1.1.3, below.

Figure 1.1.3: AIBO, a robotic dog used with children on the autism spectrum (Kahn, 2011)

In children on the autism spectrum, robotic animals have shown the potential to improve their verbal engagement and interaction, even without the AR having any programming to allow the animal to respond (Kahn, 2011). Studies have shown that the simplified features of these designs cause children to perceive them as more friendly. Additionally, the simplified features may allow children to focus more on the skill being trained (Peca, et al., 2014). AR is not only useful for those with disabilities. They likely will assist caretakers with simple tasks or full-time, depending on the needs of those with disabilities. As there is an increasing need for caretakers but a decreasing number available, AR may fill a gap for those living at home as well as those in assisted living or rehabilitation centers to augment the quality of care for those with a disability (Abdi, et al., 2018).

For AR to be successful elements in the lives of those with disabilities, a variety of factors must be further examined (Wang, et al., 2003). Integration of robot use into the lives of those with disabilities and their family members and caregivers must be closely examined to determine how best to adapt to this new technology. How those with disabilities interact with different types of robots will influence the determination of what types of robots best meet the needs of specific stakeholder groups and what would be the optimal robot design for these different groups. Lastly, the long-term impact of AR will be important for influencing people to adopt AR in the future. Each of these will be examined more closely in subsequent chapters.

Section 1.2: Major Stakeholders

Children with disabilities can benefit greatly from AR. They have typically been tested for use with students with cognitive disabilities at school. They can improve learning by retaining focus, helping with social cues, and other ways (Cook, et al., 2010).

The aging population can also benefit from AR. The increasing number of elderly Americans is a key factor for making this demographic a major stakeholder (National Research

Council (US) Panel, 2001). Various healthcare services needed by the aging population can be addressed with AR making them prime users with respect to ameliorating the effects of dementia, mobility problems, and loneliness.

AR can also cater to persons with disabilities (PWD) in need of rehabilitation to recover normal motor function (Zhou, et al., 2016). PWD in need of rehabilitation services include people with traumatic brain injury (TBI) and those sustaining a spinal cord injury (SCI). The Brain Injury Association estimates that each year more than 2 million people sustain a brain injury, and 373,000 of these are severe enough to require hospitalization. TBI ranks as the leading cause of death and disability among children and young adults (Institute of Medicine, 1997). The National Spinal Cord Injury Statistical Center at the University of Alabama at Birmingham estimates that there are between 7,600 and 10,000 new cases of SCI each year (Institute of Medicine, 1997). The people in both categories often suffer from motor impairments that affect activities of daily living, which could be aided by AR. In addition, the most frequent age of onset of TBI and SCI is as young adults of working age, thus requiring assistance much longer than conditions that typically occur later in life, such as heart disease and Alzheimer's disease (Stabile, et al., 2012).

Section 1.3: Children with Disabilities

Children with disabilities often need additional assistance in schools to improve learning. AR can benefit these students in their learning. Studies show that around 20% of students have a reading difficulty and roughly 5-8% have dyslexia. AR can help the 20% of students with reading difficulty (Svensson, 2019). This can also in turn improve other areas of their education. For students with a learning disability, mathematics proves to be more challenging. A report published by the National Center for Learning Disabilities documented only 8.4% of fourth graders and 4.1% of eighth graders with a learning disability scored proficient or above in mathematics (Gersten, 2009).

If AR is to be a part of the educational environment, they will need to be used as a way to improve functions and encourage learning with children with special needs, especially in the school environment (Suchitporn, 2018). Teachers have stated that managing a class, even with another teacher's aide present, is still difficult due to additional time needed for children with disabilities to complete certain activities (Encarnação, 2017).

While AR is becoming more popular, the cost can be of major concern to people. There are two different costs to take into account, initial cost (system integration/device cost) and operational cost. It was found that almost half of parents of children with disabilities felt their child was not receiving equipment or services needed, due to not having a way to pay for it (Mitra, et al., 2017). Scientists calculated the comprehensive costs families and children with disabilities, as they enter the labor force, incur to be an average of $30,500 per year per family (Stabile, et al., 2012). This is a critical finding because the benefit of the use of new technology can be weighed by looking at how much it saves a family who is living with a disabled child. Along with other factors, this means that finding a reasonable cost for AR is essential before implementing said technology on a large scale.

Section 1.4: Aging Population and Adults with Disabilities

There is an exponentially increasing number of people joining the aging population, which is not proportionate to the number of individuals needed to take care of them. By 2050, those experiencing dementia will have reached 131.5 million (Abdi, 2018). This creates a need for assistance that can aid caretakers and the aging population in their day to day lives. Without assistance, there will not be enough caregiving resources available to assist the large and continuously expanding aging population. By 2050, the aging population is expected to reach a total of 2.1 billion, compared to 901 million in 2015. Simultaneously, the number of social and health-care providers is decreasing (Abdi, 2018). Furthermore, many members of the aging population would like to remain in their homes as long as possible, but cannot do it with the current resources available to them. More than 90% of Americans 65-74 year-old and 95% of those older than 75, who are living in single-family detached homes, wish to remain at home as long as possible (Benefield, 2014). This objective is referred to as “aging in place”.

The growth of the aging population needing assistance combined with the lack of available care providers creates a need for AR to fill this void. Over 70% of the aging population over 80 years old experience limited mobility. AR could be a concrete solution to reducing the burden of caregivers, clinicians, and nurses by allowing them to devote their energies to less tedious tasks and enable them the opportunity to be more socially interactive with those in their care (Firorini, 2019).

The cost of AT is a potential concern to members of the aging population. Again, the initial cost and operational cost must be taken into consideration. Nearly one third of all baby boomers and older individuals are not willing to pay anything for technology that would help them with kitchen tasks or personal care when asked to assume that they needed help in these areas. Those individuals who might be willing to pay some amount per month out of pocket for AT would still likely need to rely on other forms of payment to fund expensive AT devices. Among those willing to pay some amount, the mean amount respondents were willing to pay per month for kitchen technology was $40.34 (median = $25) and for personal care technology was $44.96 (median = $25) (Schulz, et al., 2013). Although only a small sample, 100% of those individuals in the study who had one or more ADL impairments were willing to pay something for the technology (Schulz, et al., 2013). This finding suggests that attitudes about willingness to pay might change as awareness of impending disability increases.

There are many different ways the aging population can pay for AT (Assistive Technology, 2020). Out of pocket is the least common but still a potential way to fund the use of this technology. Unfortunately, no single private insurance plan or public program will pay for all types of AT under any circumstances. Medicare Part B will cover up to 80% of the cost, if the AR is considered durable medical equipment. Depending on location, state-run Medicaid program may pay for some AT, but some of this may come out of pocket. The Department of Veterans Affairs may help older adults who are eligible for veteran benefits. This does not cover all of the aging population but it is beneficial for those eligible. There are some subsidy programs that offer some AT at a reduced cost or free. Lastly, businesses and nonprofit groups may offer discounts, grants, rebates to get consumers to try certain products. These are all potential ways the aging population could acquire AT if it is needed.

Section 1.5: Rehabilitation Care

PWD are in need of improved access to rehabilitation and improved delivery of care. In traditional settings, there is a one-on-one interaction with a therapist, usually at a treatment center. AR allows for an objective assessment through the use of rehabilitation robots that collect motor function data. Additionally, AR can transform rehabilitation into a more widely accessible enterprise by allowing people to receive quality rehabilitation remotely. The AR would be able to provide therapy consistently, while continually collecting data to track progress, and then to send results to therapists for remote follow-up. Automatization of therapy can fulfill the need for people to be treated simultaneously and possibly even remotely, in the comfort of their own homes, through telerehabilitation (Laut, 2016).

There is a lack of accessibility to outpatient rehabilitation services for PWD. Their accessibility to rehabilitation care is limited by location and availability of rehabilitation centers, cost of therapy, and transportation to rehabilitation centers. This is a problem AR can help solve (Luc de Witte, et al., 2018). One of the participants in a study on the barriers of the health system to rehabilitation services for PWD described accessibility to rehabilitation centers as a great problem for PWD (Abdi, 2018). In rural or low income areas, rehabilitation centers are scarce. In addition to physical accessibility, financial accessibility is of concern to many because rehabilitation services are expensive (Abdi, 2018). PWD have a problem with the nature of available rehabilitation care. Care is often segregated and this hinders their integration into their wider community. PWD are often confined to rehabilitation care facilities and this inhibits their interaction with society. Institutions have largely neglected the need both to integrate people with disabilities into their wider community, and for community attitudes themselves to be rehabilitated or changed to facilitate this integration (Jackson, 1988, p.39-53). AT can potentially help facilitate the integration of PWD into society as they can receive care in their homes and more portable forms of AT for rehabilitation.

When undergoing rehabilitation individuals must be concerned with two costs ; direct medical costs (in-patient and out-patient costs) and indirect medical costs (e.g. hospital administration costs). The cost of rehabilitation largely depends on the nature of the disability and what medication and care is required. Adequate insurance coverage and out-of-pocket payments are main concerns in many numbers of rehabilitation services to PWD. For stroke rehabilitation, costs reach an average yearly rate of $11, 689 (Institute of Medicine, 1997). For traumatic brain injuries, costs range from $17,015 for mild injuries up to $133,467 for more severe injuries. Follow up charges for rehospitalization, physician visits, medications, attendant care, and attendant care ranged from $2,323 up to $54,701 over a span of 4 years after rehabilitation (Institute of Medicine, 1997). For spinal cord injury, initial hospitalization costs reach $95,000, with additional costs coming in the form of having to modify ones' home, yearly medical services, supplies and adaptive equipment, and personal and assistive care (Institute of Medicine, 1997). However, the outpatient costs of stroke rehabilitation and brain injuries estimates the average cost for outpatient stroke rehabilitation services and medications for the first year of outpatient rehabilitation discharge was $17,081. The corresponding average yearly cost of medication was $5,392, while the average cost of yearly rehabilitation service utilization was $11,689 (Godwin et al, 2011). Comparing incurred costs between 1997 and 2011, it is evident from the above costs that the cost outpatient stroke rehabilitation has increased over the years and will continue to increase. AT can potentially reduce the costs of outpatient stroke rehabilitation services because the frequent presence of rehabilitation nurses and staff may not be needed.

Section 1.6: Conclusion

AR has the potential to be particularly impactful for three major stakeholder groups: children with disabilities, the aging population, and people undergoing rehabilitation. Many children with disabilities have specialized educational needs that could be performed by AR. This need is different from the other stakeholders' needs because these children require a formal education comparable to nondisabled students. A study done by the Disability Statistics Rehabilitation Research and Training Center showed that around 70 percent of students with disabilities spend a large amount of their classroom day in class with nondisabled students (U.S. Department of Education, 1997). Therefore, AR needs to seamlessly integrate within the current educational system while providing specialized learning for students with disabilities.

With the aging population, many are either not able to take care of themselves or need assistance in order to live independently. The aging population often has difficulties performing home tasks and personal care, which is reflected by a higher rate of home accidents (Czaja, 1990). The use of AT could help reduce the number of accidents, which in turn could help improve the quality of life for the aging population, and could also help decrease the amount of hospital visits.

Lastly, people undergoing rehabilitation require specific care that is not always easy for the family to accommodate depending on their location. The need of this group is to have improved and more accessible care. People undergoing rehabilitation require assistance in regaining motor functions or mental abilities lost due to injury or disease. The use of AR could help standardize treatments, cut down on transportation needs, and provide feedback to caregivers, which could potentially result in needing less in person meetings with caregivers alleviating their need to take off work. With this large population of stakeholders, millions will be impacted by the future of AR. We simply do not have enough people to take care of those in need. The implementation of this emerging technology could potentially be tremendous cost savings for a family, patient, or simply reduce the amount of caregiving that is needed. Therefore, further research within the AR field is critical for the future of our society.

Chapter 2: Physical and Social Interaction between Users and Assistive Robots

Brittany Allen, Sahar Ibrahim, Elizabeth Manes, Maria McCoy, Lakmini Wilson

Section 2.1: Introduction

There are various different categories in which assistive robots (AR) can be incorporated, so a well-defined process for properly integrating AR into an individual's life is critical to successful implementation. In this section, we discuss several important aspects for the successful integration of assistive robots: training the user, training the robot, home integration compared to facility integration, assistive robots' role with professional caregivers, and users' perceptions of assistive robots.

In regards to the user's flexibility and adaptability with AR, there are several concerns about the complexity associated with their use. Specifically, training and usability issues involving human-computer interfaces, steepness of the learning curve for different end-users, and preferences on the design of the interface (voice recognition, joystick, etc.) are all critical to ensuring successful user-robot interaction (Victores et al., 2010). On the other end of the user-robot relationship, there are situations where robots will need to be trained on how to act with different individuals. For example, in settings with socially assistive robots (SARs), therapists need to be able to tailor the robot to individuals for effective learning and safety. In order to properly integrate SARs, they will need to be accessible for people without significant coding experience to modify and train them (Barakova et al., 2012, p. 704).

AR can be utilized in a variety of settings including within a person's home and within larger care facilities. Variability in training and use in each of these two environments must be acknowledged and assessed when looking at the overall integration of assistive robots within a user's daily life (Abdi et al., 2018).

When determining how AR would affect stakeholders, it is important to properly define the relationship between robots and professional caregivers. The robot should have different levels of control based on the need and the nature of the task without compromising the effectiveness of professional caregivers (Bedaf et al., 2017).

The user's perceptions on the impact and usefulness of AR are necessary to take into account when determining if the device will have a positive impact. A general lack of familiarity with new technology can cause a user to feel uncertain and could have a negative impact on the user's overall experience. Overall, there are social and technical barriers to integration to overcome before assistive robots will be fully incorporated in users' lives.

Section 2.2: Training the User

An individual's receptiveness towards AR is dependent on the efficacy of different user interfaces and training procedures. Factors that are commonly evaluated include user acceptance, security, precision of task execution, dependability, and overall system efficiency. However, boundary conditions such as the steepness of the user's learning curve as well as the environment in which the user occupies can affect adaptability of the user-robot relationship (Victores et al., 2010).

As many caregivers are concerned with usability issues associated with computer interfaces due to patients' ranges in technological experience (Pino et al., 2015), interfaces utilizing voice recognition, joysticks, touch and/or button selections are highly recognized (Victores, et al., 2010). Research at the Assistive Robotics Laboratory at the University of Central Florida (UCF) developed a graphical user interface (GUI) that could be operated using such interfaces (a mouse, a track ball and jelly switch, a head tracker, or voice recognition), and evaluated the importance of various components to a user. Preferences for interfaces with a robotic assistive device fell into six areas and were ranked accordingly: safety (30%), simplicity (25%), responsiveness (20%), accuracy (10%), reliability (10%), and customizability (5%) (Hazlett-Knudsen et al., 2011). The basis of these areas were characterized on preventing the user from impossible actions, minimizing user action for function of the robot, displaying relevant dialogue/information, acknowledging user entries immediately, responding the same every time the user does the same actions, and minimizing system errors (Hazlett-Knudsen et al., 2011). Thus, implementation of such tasks in accordance with any of the user interfaces, would likely increase usability.

It has been shown that successful task engagement can be correlated with overall positive views and performance with the interface (Tsiakas et al., 2018). To increase familiarization and subsequently a positive experience with the robot, it is important to provide the user with background information and a previous demonstration of the interface system (Parsons et al., 2006). Despite considering the correct interface as well as the training procedure associated with it, parameters regarding user learning curves and comfort with technology are vital (Victores et al., 2010). Therefore, considering the various differences from user to user, an interface that can update towards human-generated feedback would be optimal for personalization (Tsiakas et al., 2018). However, a more simplistic route could be building on simple/natural dialogue and feedback from the robot on tasks, providing good error messages and/or minimizing the number of user tasks for functionality. We will examine more in depth on simplifying robot training later in the next section. But, an individual’s likelihood of accepting and adapting to an AR depends greatly on the type of interface, its components, and the ease with which it can be utilized.

Section 2.3: Training the Robot

While training the user on how to use an AR is an essential part of the integration process, it only covers one direction of the relationship between the robot and the user. It is important that robots can adapt to the different preferences and needs of their user. In fact, 40% of survey respondents felt their lack of experience with technology would inhibit them from wanting to incorporate an AR into their life. Many times, people are intimidated by the technology they are not familiar with, so being able to have a product that adjusts to individual users would help people enjoy the experience of interacting with the assistive robot. In some clinical settings for socially assistive robots, it is even a matter of safety and effectiveness for the robot to be adaptable to the user. In the past, robots have been set in a way that allows programmers to make changes to the robot's settings, but this makes integration complicated (Barakova et al., 2012, p. 704).

Requiring professional help to train a robot to the needs and habits of its user makes the integration process inefficient as it adds multiples steps: the user would need to identify what they want from the robot, contact the company that can provide assistance, wait for them to send an experienced coder, and sit for an appointment where the adjustments are made. All of this extra effort and time is due to the gap between the level of understanding that the average user would have with computer science and the knowledge that is necessary in order to code changes to the robot.

This gap will need to be addressed differently in each context. First, in clinical social therapy settings, the solution would be to create "end-user programming architecture...that is easy to understand and generalize to different situations" (Barakova et al., 2012, p. 704). There have been some developments in programming architecture that makes it more user-friendly for the inexperienced user, and it has been applied in a setting where therapists can make adjustments for each of their clients (Barakova et al., 2012, p. 711). More developments are needed before this technology is ready for market, but this component of socially assistive robots is important, because it is expected that allowance for end-user programming will increase the number of therapists willing to incorporate AR in a clinical social therapy environment (Barakova et al., 2012, p. 706). In the context of teaching children skills using socially assistive robots, flexibility to change settings based on what the therapist is intending for the child is essential. There are some topics that are necessary for older children to learn about and inappropriate for younger children to be exposed to, and there are bound to be child-specific sensitivities that could not and should not be accounted for in developing the robot, but nevertheless should be edited before the therapist sees that child. So, these are cases where the ability for the end-user to program the robot is a requirement for integration, not just for improved efficiency (Barakova et al., 2012, p. 706).

In contrast, there are many cases where the robot learning about its user is not solely about performing tasks, but still critical to the integration process. There was one study that looked at how a robot can adjust its "personality" to adapt to the user's preferences. They found that users will "tune the system" to its "optimal interaction" (Gopinath & Argall, 2017, p. 247). This insight saves time and money for those developing assistive robots to know that for integration to be successful, it's not about finding the most popular robot personality for every user, but creating a robot that can modify itself and have the perfect personality that could be slightly different for each individual user (Gopinath & Argall, 2017, p. 248).

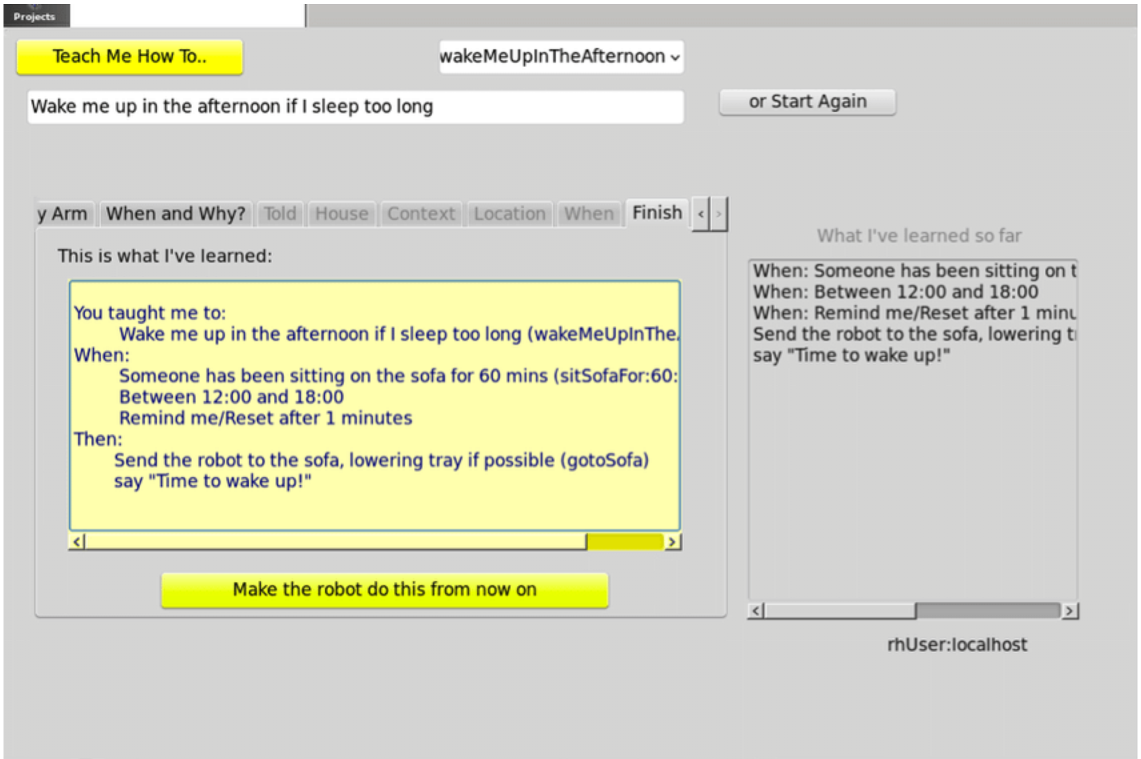

Figure 2.3.1: User interface example for creating task settings on an assistive robot (Amirabdollahian et al., 2013)

The user interface depicted in Figure 2.3.1 is called the “TeachMe-ShowMe interface” (Amirabdollahian et al., 2013). There are many computational requirements for each setting, so there are a limited number of settings that the user can change in the robot. The great thing about this interface is that it does not show those technical components; it lists in plain English what tasks the robot has learned. It also provides an opportunity for the user to easily select what they want to teach the robot next. There are design attributes that could be improved for fast and easy comprehension, but this interface is a suitable reference for a platform that allows the non-computer programming user to train their AR.

In any case, for the best case situation in regards to training the robot, the end-user needs to have control. In order for this to happen, AR creators need to set up key features that can be modified and an easily learnable user interface. This way users, therapists, or caregivers do not need to contact a technical team to adjust the robot to each user's needs.

Section 2.4: Comparing and Contrasting Integration in the Home to Integration in a Facility

Integration of assistive robotics will vary depending upon the environment in which the integration is occurring. The two main environments, implementation at home and within a long-term care facility are where the aging population will spend most of their time. These are the environments where older adults are likely to spend most of their time. Implementation of an AR in public spaces, such as stores, parks, or airports, has many variable conditions that would make programming very difficult. In addition, the user will have more time and privacy to become acclimated with the AR within their home or care facility than they would solely using the AR for guidance within a public place. Although implementation of an AR within a public space is an important concept to be researched, the scope of this report will focus on the two environments noted above. Implementation at home will provide different challenges when compared to integrating an AR in a care facility.

Integration within the home can vary depending upon the accessibility the user has to additional caregivers. A person can potentially live alone with no assistive personnel, but they could also have family caregivers or professional home healthcare workers to provide assistance at different times throughout the day. However, regardless of the assistance present, integration within the home is dependent upon the focus and willingness of the user. An assessment of the user would need to be completed to determine the user's level of comfortability utilizing any form of technology, their preferred interface design when communicating with the robot, and the tasks they would envision the robot would be helpful for. In addition, in order to best fit the user, information would need to be gathered about preferences of the robot’s overall aesthetic, size, and mobility. By catering the AR to best fit the user, the transition to adding the robot into the home should move more smoothly. Currently, robots with a limited set of functionalities have been tested long-term in natural environments. However, advanced robots that assist in a more wide range of tasks have not yet been tested over an extended period of time within a natural environment (Frennert et al., 2017). In order to implement advanced robots within the home, long-term testing must be carried out to determine the opinions and acceptance of the users. From such a study, various determinations could be gathered about user preference of the look, communication style, or technicalities of the robot. From a study assessing the appearance of various robots, it was determined that people who are elderly prefer robots that are not overly bulky, have some human traits but do not resemble humans, but the robot is expected to mimic certain human behaviors (Wu et al., 2012).

Incorporation of the robot into everyday life poses an additional set of obstacles to be considered. Many users want to understand the actions and interactions of the robot to limit feelings of being overwhelmed, anxious, or insecure about the user’s ability to control the robot. These anxious and overwhelming feelings often stem from user misunderstanding of the technicalities of the robot. For example, in one study, the robot had a ‘rest function’ that was intended to be utilized when the user left the home or was sleeping, but some user’s would employ the rest function when they wanted the robot to charge, and it would miss appointments or other obligations (Frennert et al., 2017). By bridging the gap between the robot and the end-user by helping the user better understand the functionality of the robot, misinterpretations and miscommunications would decrease, and the user would feel more secure and less anxious about keeping the robot in their home for the long-term. In addition, it is important to carry out many trials before sending the robots to market. By analyzing misinterpretations and reprogramming robots to be more user-friendly, the end results will be much more useful and limit the potential of the user stopping incorporating the robot all together.

Integration within a long-term care facility provides both similar and differing considerations to be explored when implementing an AR. Primarily, nursing assistants are the main point of care and communication for residents within care facilities. However, the turnover rate for care facility staff is high because it is difficult to attract, train, and retain staff that have adequate skills and knowledge to care for the residents (Castle,, 2005). In order to attend to the challenges of staffing and adequately caring for all residents, AR could be utilized to help with daily tasks. Figure 2.4.1 below depicts the types of interactions envisioned for utilizing an AR including monitoring, providing reminders, and companionship. The figure also predicts health status outcomes including physiological, psychological, and social health and acceptance and usage of this assistive technology (Castle,, 2005).

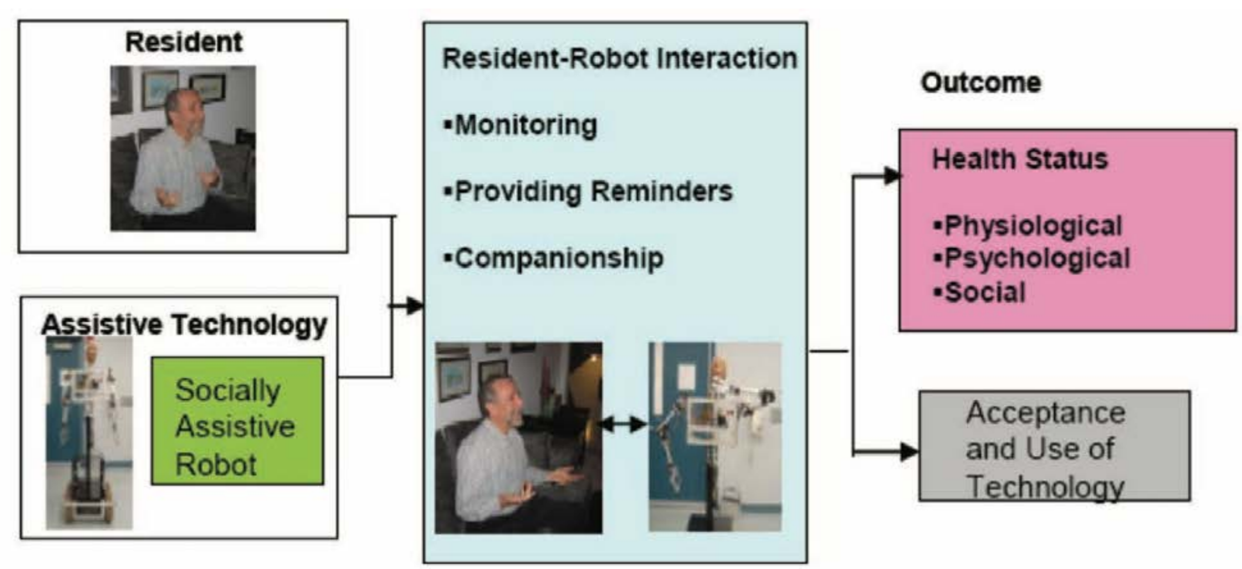

Figure 2.4.1: Depicts the interactions anticipated and outcomes of using a socially assistive robot (Nejat, et al., 2010)

When implementing an assistive robot within a long-term care facility, interactions with the robot can occur in a group setting because many people live within the same area. This could provide additional support for the user because there are additional outlets to provide assistance if the user becomes frustrated or confused by the technicalities of the robot. In addition, within a long-term facility, the staff can offer encouragement for the users to engage with the robot which decreases the potential of the robot going un-utilized by the users. By placing the robot in a more collaborative environment, the users can help one another with difficulties and learn together how to effectively integrate the AR.

In a study conducted using an assistive robot in a one-on-one setting in comparison to a group setting, the group setting provided more positive results. Eight studies were carried out within a one-on-one setting, while seven studies were in a group setting. Of the group settings, all reported positive outcomes with reduced depression and agitation and an increase in positive emotions. For the one-on-one settings, only five reported positive outcomes, while two reported negative outcomes including increased depression and agitation (Abdi, et al., 2018). In addition, the group interactions improved sociability between subjects, which can cause an overall boost in mood and morale.

Overall, there are potential benefits and additional considerations to be made when attempting to implement an AR within a user's home and within a long-term care facility. Within a user's home, it is pertinent that the user becomes comfortable with the technicalities of the robot and that they are using a robot they feel comfortable with to ensure the user does not experience additional frustration and agitation generated by misinterpretation or miscommunication. In a long-term care facility, it could be beneficial to integrate the assistive robot in a group setting to improve communication among users and boost morale and mood. However, integration within a group setting could cause less one-on-one advancement of understanding the technicalities of the robot for the user.

Section 2.5: Assistive Robotics & Their Role with Professional Caregivers

When determining how AR would affect stakeholders, it is important to define the relationship between the robots and the professional caregivers of the user. Assistive robots will have an increasing role to play in healthcare and it may be quite a challenge for professional caregivers to integrate them within the workforce. It is therefore important to understand the views of these professional caregivers on AR in order to ensure smooth integration into the healthcare setting.

Professional caregivers were initially hesitant about integrating assistive robots into the user's life. They were concerned that the elderly would be reluctant towards getting used to a new type of caregiver, and that if they had limited experience with technology, they might need help with understanding how to use the robot (Papadopoulos, et al., 2018). Another major concern was regarding social contact with the robot. Most elderly users are generally socially isolated. Sometimes the only social contact they have during the day is with the caregiver (Bedaf, et al., 2017). Caregivers felt that the most important part of providing care was the human-to-human contact. It is not only completing a certain task that is so important but the social relationship that you build with your patient. And they felt that this human connection creates the best atmosphere to stay at home and promote aging in place (Caregiver, personal communication, March 26th, 2020). Therefore, they were concerned that if the professional caregiver was completely replaced with an assistive robot, the elderly would retrieve from social contact altogether and fall into social isolation

An AR would potentially play different roles in a healthcare setting. It is unlikely AR would completely replace the professional caregiver and be able to complete all their care activities. However, AR could act as an assistant to the caregiver and help them during off hours or complete specific separate tasks. Integrating AR into a healthcare setting to augment existing care performing minor assistive tasks without replacing the work of others was found to be more acceptable (Support Professional, personal communication, March 26, 2020; Papadopoulos, et al., 2018). The professional caregivers were not comfortable when the robots carried out nursing/caring activities particularly feeding, assisting with physiotherapy and other general nursing care as they felt that the robots could unintentionally hurt the user and cause even more harm (Kemenade, et al., 2015). As AR do not have human intuition, if they were used to complete major nursing/caring activities they may not be able to always recognize potential problems or completely analyze an individual (Support Professional, personal communication, March 26, 2020). Robots would analyze things as black and white and would be unable to see the gray areas, so they were not found to be smart enough to complete such complex tasks (Papadopoulos, et al., 2018).

However, the professional caregivers did mention specific caregiving tasks that an AR would be helpful, including fetching/carrying objects, contacting others in case of a fall or other emergencies, opening doors, or meal preparation (Bedaf, et al., 2017). Having the assistive robots complete such separate tasks would help to reduce the professional caregiver’s workload and enable more independent living for the elderly (Kemenade, et al., 2015). Additionally, as professional caregivers cannot be with the patient constantly, having an assistive robot monitor the user during off hours would be very beneficial for both the user and the caregiver. AR would be able to complete simple or repetitive tasks as mentioned above, allowing the professional caregivers to focus more on the complex or more intricate tasks of daily jobs (Support Professional, personal communication, March 26, 2020).

Another barrier in integrating robots into a professional care setting is to determine what level of control the robot should have over the user. The professional caregivers feared that the robot may harm the users’ autonomy if it executes care tasks without asking permission first (Kemenade, et al., 2015). In a study that evaluated the different perspectives of seniors and professional caregivers of a service robot as well as through our survey and interview data we found that people have varying views on the level of control the robot should possess. Certain groups of participants wanted to be in control of the robot as they pressed the buttons and instructed the robot to finish the task (Bedaf, et al., 2017). They did not want the robot to have any “control” over their life and only required the robot to be able to make recommendations or give input based on the task at hand (Support Professional, personal communication, March 26, 2020). Others felt that the interaction between the robot and the user should be a cooperative effort as both of them work together to complete a specific task, while some felt that the robot was in control of them as the user just executes whatever the robot proposed them to do (Bedaf, et al., 2017). Based on these varied responses it was found that the level of control the robot should have would depend on the nature of the tasks and on the personal preferences of the user (Bedaf, et al., 2017). Caregivers especially felt that the assistive robot should try to make sure that the person can do tasks independently as possible but in cases where it is impossible, the robot should adjust to user’s need and complete the tasks accordingly (Caregiver, personal communication, March 26, 2020). This would require the robot to be flexible and extremely smart, comparable to the care that is delivered by a human caregiver without completely replacing the tasks of the caregiver to be most effective.

Section 2.6: Perceptions on Assistive Robots

Perceptions of assistive robots vary by age, experience, and level of education of the potential user. These factors could play a role in determining if the user or caregiver will choose to rely on this assistive technology. According to the Population Reference Bureau, Americans can expect to see more than a 50 percent increase in the number of individuals requiring assistive care due to the aging of the baby boom generation (Mather, et al., 2019). With the aging population on the rise, a need for alternate ways to receive assistance in the home or care facility has arisen.

Research regarding the aging population has found an overall negative response to assistive devices. However, the opinion of the aging population in general depends on the context of the assistive robots used. In a study regarding the acceptance of healthcare robots' young adults were recorded to have a positive response to this assistive technology and users 65 years and older had the most negative response. Those 75 years and older were generally indifferent to the additional aid provided by the assistive robots, and more likely to accept inconveniences instead of searching out an assistive robot or device. The study found that older people were less comfortable with advanced technology and had a preference towards less autonomous robots (Broadbent, et al., 2009).

A systematic review supported this finding through identifying factors which contributed to the perception of assistive technology. The review found that out of the aging population, around 18 percent held a negative perception of assistive devices due to a fear of dependence (Yusif, et al., 2016). According to these results, negative perceptions could be mitigated by allowing a user to have more control, or by making sure that the assistive device has a less threatening voice or physical appearance. This solution draws attention to the importance of appearance of the assistive device and the role the physical attributes of the device plays in user approval. Future developers should consider the appearance and amount of control offered to the user when creating assistive care devices.

The user's perception on assistive robots can also be affected by the amount of experience and exposure the individual has with new technology. Aversion to assistive technology prevents users from taking advantage of resources which could enable them to live more independently. Often individuals with little experience and a lack of education or training with smart technology and AR can develop feelings of uncertainty. This uncertainty has been linked to a lack of exposure to these technologies and may change over time. In the study they found that individuals with a negative overall perception of AR would rather go without help than complete the tasks with an AR. Users would avoid using the assistive robot when presented with a task (Wu et al., 2014). This suggests that just providing the technology to an individual will not lessen the problem. Users with more experience using assistive devices were able to adapt to the presented technology and complete the tasks (Wu et al., 2014).

A similar study conducted on Jeiu Island in Korea found that over time, and provided training, the individuals become more comfortable with the assistive robots, and this provides a potential solution to improve the user’s perception of AR. The training conducted was found to be essential to improving the patient's overall comfort and trust of the AR. Patients exposed to the AR for a longer amount of time, in combination with training, were more likely to adapt the robot into their everyday habits than those who had no training. Participants in this study mentioned feeling that their abilities were inadequate for using the assistive device (Koay, et al., 2007). Older adults have concerns with the ethical issues which arise when considering integration of the assistive robot and this could decrease their openness to working with assistive devices instead of receiving personal care.

Healthcare workers seem to view these AR as helpful tools which aid them when interacting with patients. In an interview with a Physical Therapy Assistant, they stated “[An assistive care facility] has all sorts of tools that they would love to purchase but they have to look at the financial aspect of obtaining an assistive robot.” She went on to explain that assistive devices are expensive and they must prove to the insurance company adequate need. Oftentimes it is less expensive to pay a certified nursing assistant to manually complete a task. According to her, an assistive robot may allow a patient to progress more quickly and help make them as independent as possible (Personal Communication, March 18, 2020).

When addressing user perceptions, both the appearance of the device and the amount of education or exposure to the device should be taken into consideration. Constructing an assistive robot to have a less threatening appearance and allowing the user more control of the device could improve the user's likelihood to interact with the device. Increasing exposure to technology can have a positive impact on an individual's overall perception of a smart device.

Section 2.7: Conclusion

Ultimately, there are several key factors that must be considered in order to successfully integrate assistive robotics. Through examining the training of the user, training of the robot, home integration, role of the caregiver, and perceptions related to assistive robots, it is clear that many factors should contribute to an effective integration strategy.

In order to provide a successful user interface, prioritizing the safety, simplicity and responsiveness of the system can ensure efficient utilization. Implementing simple tasks through the use of voice control, joystick, and/or touch/button selections, can create an easy-to-use system with high response and safety rates.

Training the assistive robots to allow customization and personalization towards the user is also a high priority. Users want to be able to tailor an assistive robot to meet their own preferences and/or needs. In order to accommodate the user, without programming experience, the user interface will need to be able to update towards human-generated feedback to create a system optimal for personalization.

Additionally, the type of living environment is important when considering when integrating successfully. Examining implementation of assistive robots within a long-term care facility versus the comfort of a user's home, must be scrutinized thoroughly. Both environments present considerations that should be explored, including the level of comfortability the user will have with the AR, and the potential benefits of AR integration within a group setting.

It is also important to consider not only the patients, but the caregivers involved in utilizing assistive robots. Professional caregivers found that AR's were most helpful when they assisted in completing simple everyday tasks, without partaking in important nursing/caring activities. Additionally, in terms of control the robot should have over the user, it was found that in order to cater to the user's needs and preferences the robot should be flexible and adapt depending on the specific situation.

Lastly, opinions on ARs can contribute significantly to implementation. Professional healthcare workers, and users 65 years and younger seem to have an overall positive outlook on the integration of ARs. However, users older than 65 years seem to develop a more positive impression after increased exposure and longer training periods when compared to the latter.

As mentioned before, all these factors are vital to developing an optimal system of ARs that succeed through the implementation process. Scrutinizing and analyzing these considerations, whether it be the robot-user relationship, the environment, or the type of user, are crucial in providing an effective implementation process.

Chapter 3: Ethical Considerations for Using Assistive Robots

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Section 3.1: Introduction

Successful integration of assistive robots (AR) is a multifaceted issue that dictates the willingness of the users to adopt AR in their homes, classroom, or other places. This mode of acceptance is based on the efficacy of the interaction. Both primary and secondary users of the assistive robots must be considered to determine optimal integration. Primary users are particularly concerned about maintaining autonomy and natural interaction. Secondary users, such as caregivers and family members, focus on the ideas of usability and efficiency. It is key to take into account both viewpoints as they will have significant interaction with AR and ultimately make the final decision in successfully adopting this emerging technology.

This chapter will detail the interactions between the AR and the user in such a way that will ensure successful integration of AR. First, it will be outlined how respect for autonomy and personal privacy translates to the integration of AR. Additionally, autonomy and freedom of decision making will be applied to the adaptability of the robotic device. This freedom of choice allows the user to interact in a more meaningful way with the assistive device.

Secondly, it will be understood how the maintenance of security of data contributes to the success of an interaction between AR and the user. To maintain privacy, it is important that the developers of the robot are ethical with how they use data acquired from the robot, and that they are transparent with the user about how the data is used.

This chapter will then outline the preferences of primary users when interacting with AR. Primary users value what physical and cognitive capabilities the assistive robot has. Users will interact in a more positive way with robots that do not have physical human characteristics. However, high cognitive functionality in robots is valued when interacting with users.

Finally, for successful integration of assistive robots, caregiver acceptance is of the utmost importance. Caregivers must feel fully comfortable with a robot's capabilities as well as its limitations to fully implement the robot effectively. Additionally, the caregiver has a different perspective than the end user, requiring a different set of standards in judging effective interaction. This includes an emphasis on usability and ergonomics of design rather than just strictly ease of use.

Section 3.2: Desire for Control and Customization

Generally, when considering assistive robots, users prefer to interact with a robotic device that can simultaneously respect varying levels of requested autonomy, and adapt to the individualized components of need. This is particularly true when using socially assistive robots (SARs) whose purpose is to elicit positive responses or behaviors from users. In contrast, task robots, such as those that perform routine tasks can be more directly controlled by users, even allowing for complete shutdown when not wanted. This ensures users' desire for overall robotic control and customization will allow for a more productive and satisfactory interaction with the user (Koutentakis, 2020).

When considering levels of control, the aging population of end users expressed strong opinions about maintaining absolute manual control over the robot. This full manual control is highly representative as an extension of the personal autonomy of the user. In order to facilitate a genuine and effective interaction with an assistive robot, it is important to establish a level of trust between the user and the robotic assistant (Langer, 2019).

When investigating the potential use of the assistive robots among the aging population, it was found that there was a level of fear injected into their perspective of interacting on a daily basis with the robot. When asked how this interaction could be made more comfortable for them, there were two primary categories of answers. First, the idea of full control of every robotic interaction takes major priority in the minds of the aging population. A previous study investigated what manual control meant to the users of the assistive devices within their own home. It was found that the users desired the ability to turn the robot completely off at any time. The alternative of putting the robot into “rest” mode was insufficient (Lee, 2018). The aging population needs a device to fit into their desired lifestyle, not overtake their lifestyle. It remains important to the users that they get to decide when and where their AR should be utilized. Additionally, it was found that the users wanted their assistive robots to be able to comply with all directives, regardless of whether or not the robot computed the request as a “good decision” (Lee, 2018). In order to have the users feel comfortable and secure in their interactions with the assistive robotic devices, it is important to allow for full manual control of the robotic devices to a level that is appropriate with the users’ cognitive ability and awareness.

The second major category involved with respecting the autonomy of the user to enhance the interaction is the idea of boundaries. These boundaries were broken down into physical boundaries and informational boundaries. As found in a previous study, it is important to the users that they could control where the robot was able to go within their homes. In fact, it was found that all participants taking part in the study desired the ability to make sure that the robots did not leave their docking stations while the users were not in their house (Frennert, 2017). Breaking that physical barrier removes a level of autonomy that the aging population desires. It is important to the users that they feel respected and in control within their place of residence. By creating an AR that respects these desires, the interactions between the user and the robot will happen more frequently, and with a greater level of trust.

Additionally, informational barriers were brought up as an area of concern for the users of the aging population. Due to the nature of an assistive device, sensitive information may need to be shared with the robot in order to maintain a quality level of care. However, when this concept was investigated in *Autonomy and Dignity: Principles in Designing Effective Social Robots to Assist in the Care of Older Adults*, it was found that it was important to the users to be able to decide what was shared. The users expressed the desire to be able to communicate with the robot what information can be considered appropriate to share with other people, and what information is inappropriate. Additionally, it was found that by allowing this open channel of communication, users felt that their privacy as an individual was being respected (Wilson, 2016). This desired interaction creates a level of trust between the user and their assistive device. By respecting the physical and informational boundaries set by the user, a better relationship is established between the user and the assistive robots.

When considering levels of customization of the assistive robotics, increased adaptability of the robot influences the efficacy of the robotic interaction both within the aging population, and for those with cognitive disabilities. The level of customization may pertain with types of functions the robot is able to accomplish, as well as modules the user is able to change in order to reach an end goal.

When considering the successful adoption of AR in conjunction with the aging population, allowing for adaption of functions of the AR is important to facilitate effective interactions. For example, users expressed that it would be preferable if the robot had the ability to adapt to the current status of the user. They gave the example that it would be more effective if the robot could assess how the user felt, and give suggestions like drinking more water, or taking a rest. Additionally, the users felt that the robot should be able to adjust to their individual needs (Torta, 2014). This is a poignant point when considering how the AR interacts with the aging population. For example, a user with full physical autonomy may feel frustration if the assistive robot was designed only to complete manual tasks, such as assisting in dressing or bathing, and lead to a negative interaction and association with the AR. However, if this same robot was able to adapt to its user, and provide functions of reminders and informational assistance, the interaction would be optimized, and provide a positive association for its user. Although this autonomous adaptation may seem counterintuitive to the previously discussed manual control that the users want to have, they can exist simultaneously if certain adjustments are made. For example, the AR should still be equipped with the full ability to be fully turned off as the user wishes, meanwhile still make necessary adjustments according to the user's needs. Additionally, while the AR can make necessary adjustments to the user's needs, the user must still be able to deny the suggestions made by the AR. Taking the example that was given in the study, if the AR recognized that its user needed to drink more water, it could adjust by making this specific suggestion more often. However, the user would still be granted the autonomy to ignore these suggestions. Additionally, if the user felt that these suggestions were negatively influencing their daily lives, they would be capable of turning the device completely off.

For users with cognitive disabilities, the idea of modular robotics becomes important. Socially assistive robots have been studied for potential use in behavioral therapy for children with autism (Mataric, 2017). During these investigations, it was found that when children were given control over their reward stimuli, their behavior changed in a positive way. For example, some children chose to have the robot move in response to sustaining eye contact, some children chose an auditory stimuli, and some children chose a visual stimuli. After utilizing these individualized changes, it was found that the children had better reactions during play time (Fischer, 2018). By allowing users the ability to customize their robotic interactions, the ability of the AR to leave a lasting positive effect on the user increases.

Section 3.3: Privacy & Transparency in Assistive Robots

When investigating how the robot will interact with the human user, it is important to account for the impact the robot may have on the user's privacy and any other ethical concerns in regards to data stored by the robot (Heuer, 2017). To investigate this, it is first important to determine what types of privacy concerns may exist when using AR. In the development of the AR, a fully capable robot will have some sort of sensing capabilities. These sensors may include using cameras with software that evaluates the data the camera is transmitting and informs the robot what to do. Thus, how this visual information will be used and/or stored is vitally important to understand. Second, if the robot uses voice assistance, it will also need an audio recording device that is active at all times in case the user needs assistance. Along with the audio and video, it is important to investigate what the robot as well as the robot manufacturer is doing with the data that it records. Each company will need to make the decision about how they will monitor the robot as well as how the robot monitors its environment. If the data is not used responsibly, or there is not enough network security, privacy can be compromised when using AR in people's homes. It is also imperative that manufacturers are open and honest with users of the robot that they know what type of sensing data is being used.

If the robot is moving around its environment under its own control it will be using video to navigate the environment, or to perform simple tasks that help the user. Most users will be using the robot in their own home, where they have the most privacy, and if a robot is recording at all times it will impede on that privacy and record the actions that the user is undergoing within their own home. This is why 12% of users resisting participation in a study involving AR cited privacy as their main concern for not participating (De Graaf, 2017). This shows that it is vitally important that users understand the risks involved with an AR and what will be recorded through the robot technology, otherwise there will not be as much interest in AR due to very legitimate privacy concerns.

Similar to this, audio recording will be prevalent in assistive robotics as well. In any form of robot that uses voice commands, the robot will constantly be passively recording the sounds around it and when a voice command is used, the robot will be actively recording. This means that the data will be transmitted, analyzed, and stored from everyday conversations that happen near the robot. However, they will not be designed to store large amounts of data and access it; like Amazon Alexa™ the device would likely always be on and processing data within a “cloud” or a network of servers which manages the data (Privacy International, 2020). The device must always be on as the AR waits for a voice command that is used to result in a robot action. Once the robot is activated, it begins to “actively” record rather than “passively” record. Meaning, instead of listening for a specific queue, i.e “Alexa”, the AR is actively listening and compiling the data to respond to any voice request. Obviously, this concern adds another level to the privacy concerns stated above. This leads to privacy being the second most common concern mentioned when using AR (Fig. 3.3.1) (Beer, 2011).

Table 4. Most commonly mentioned concerns (*N*=124 codes)

Concern	% of times mentioned
Etiquette refusing / ending call	18%
Privacy	15%
Less personal / lack of face-to-face contact	13%
Misuse / overuse	12%
Difficult to use	9%

Figure 3.3.1: Most frequently cited concerns with assistive robots

Not only is it a concern that the company who makes the robots and the robot itself will have this data, but there is also a concern that these types of devices could be hacked into by unwanted visitors. If there is not a proper security system on the robotic device, the data being transmitted could easily be hacked into by an outside source and used as a form of spying or invasion of privacy. If this robot is remotely hacked, an outside person could use the AR as a spying device for use in a robbery, blackmail, watching, and countless other harmful activities. While evaluating the current market of AR, it has been found that many robots currently have subpar security that is vulnerable to being attacked (Denning, 2009). Currently, the standards for AR security are not as high as other personal computers. It is very important that this security issue is resolved before AR becomes even more prevalent throughout homes.

What this all concerns is that it is very important for AR to have transparent communication about the privacy concerns involved with the robots, and also that security is state of the art so that users still feel comfort and safety in their own homes. Users should know that the robot will record video and audio and must authorize that this is allowable in their homes. Also, it should be mandatory for these robots to have on and off switches that the user can use at any time. Companies should also implement up-to-date and strong security methods that will prevent any hacking or security breach. It is up to the company to be responsible, use the data they correct in an ethical way, and do as much as they can to protect the privacy of the users of their devices. With these concerns addressed and safety measurements implemented, it is expected that more users will become comfortable with having an AR assist them.

Section 3.4: Value of Human Characteristics in Robotics

When designing an AR, understanding the physical and cognitive capabilities required for it to accomplish a job is important in developing the robot’s overall design. Evaluating how users will interact with the robot is valuable in understanding what the threshold is for how humanoid an assistive robot should appear. In general, users prefer to interact with assistive robots that have relatively humanoid features, up to a certain extent. Instead of looking very humanoid, users generally prefer robots with machine-like appearances (Tinwell, 2011).

However, in terms of the cognitive features of these AR, users have a preference for interacting with robots that have humanoid-level cognitive thinking and social interaction skills (Ariani, n.d.).

The physical design of AR is necessary to ensure that the user is comfortable using it on a daily basis. The “Uncanny Valley” concept shown in Figure 3.4.1 proposes the idea that as a robot’s appearance and actions become more humanoid, people’s emotional response will become increasingly positive, but only to a certain point (Caballar, 2019).Once this point is crossed, the robot’s appearance will make the user feel strange and uneasy. This is because facial movements of even the most human-looking robots will still portray subtle deviations from the human norms. These subtle physical deviations are oftentimes perceived as odd and unsettling by users (Tinwell, 2011).

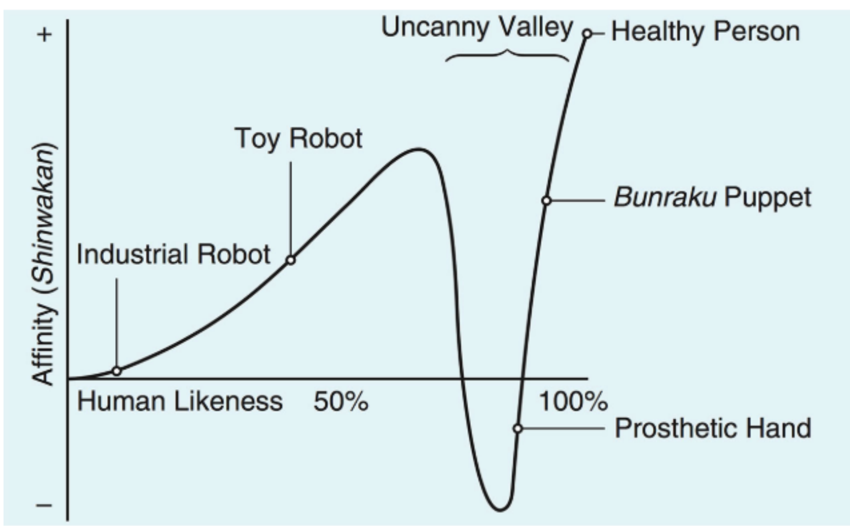

Figure 3.4.1: The Uncanny Valley graph depicting the affinity towards a robot as its human likeness increases (Caballar, 2019).

Figures below depict the physical characteristics of different examples on the Uncanny Valley graph. These include an industrial robot, a toy robot, a prosthetic hand, and a bunraku puppet.

Figure 3.4.2: Industrial robots have a low human likeness, and therefore a small, positive affinity (Staff, 2019).

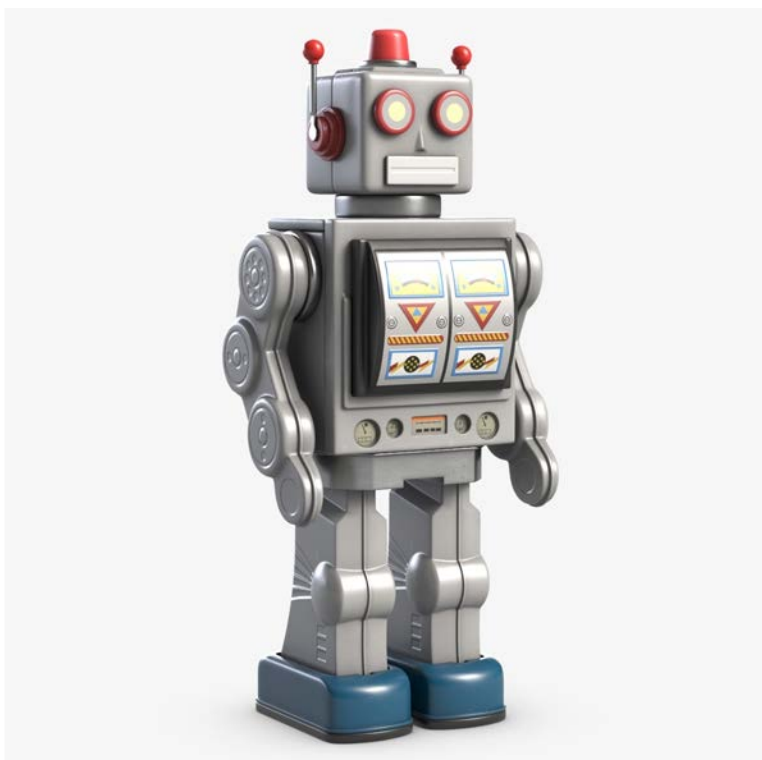

Figure 3.4.3: Toy Robots have a less than 50% human likeness and therefore a relatively positive affinity (shiva3d, & products, 2018).

Figure 3.4.4: Prosthetic Hands have a higher than 50% human likeness and therefore a small, negative affinity. This robot is a part of the Uncanny Valley (Schembri, 2018).

Figure 3.4.5: Bunraku Puppets have nearly 100% human likeness and a relatively positive affinity. This robot is a part of the Uncanny Valley (Bunraka Puppets, n.d.).

The Uncanny Valley concept is at a different threshold for different people. For example, "Children's perception of robots' appearance indicate that the robots with the more humanoid features (e.g. a human body shape, eyes, a mouth etc.) to be more aggressive, while they considered the robots with more machine-like features (e.g. wheels, tracks, no facial features etc.) to be friendlier.” (Li, 2010). Understanding what these trends are is important when designing robots that users will want to interact with and make them feel comfortable. Humanoid features in robots can provide a sense of comfort and regularity for users; however, if a robot acts too much like a human, the user may not enjoy interacting with it (Caballar, 2019). Overall, preference matching needs to be done for each type of AR and each user to understand where this Uncanny Valley lies and to maximize the users experience with the robot. Each user may have customization preferences of what they want their robot’s aesthetics to be. Understanding what these preferences are will help manufacturers develop each AR to have the preferred aesthetics and avoid the user’s Uncanny Valley

Additionally, many users find the social interaction characteristics of an AR to be valuable (Toumi, 2013). Users have a preference of interacting with AR that have cognitive humanoid tendencies. Regardless of a robot’s intended function, studies have shown that any cognitive thinking in a robot has resulted in positive interactions with the user (Kim, 2012). In a study conducted with spinal cord injured subjects using assistive robots, a conclusion was made that “disabled users tend to see the robot not merely as an agent to retrieve objects but also as a quintessential tool to reassert their domain of interaction with their environment as well as engage and exercise their cognitive faculties to the fullest” (Kim, 2012). This type of interaction is valuable for users who do not have regular human interaction. There is value in providing social interaction to users through AR as well as helping them perform their everyday tasks (Toumi, 2013).

In terms of what cognitive capabilities an assistive robot should have, user preferences should be taken into account. While some people may want an assistive robot with a high level of interaction and memory, others may prefer the robot to have a low level of interaction and short term memory (Canal, 2018). These preferences can be determined through adjusting the artificial intelligence in the robot allowing it to be tailored in its tasks and social interactions according to the preferences of the user. “More natural interactions between human and rehabilitation robots can be achieved by equipping the robots with short-term memory, long-term storage, words and language databases." (Ariani, n.d.) Having natural interactions between assistive robots and users indicates a preference and desire for robots to act more closely to humans. In terms of cognitive capabilities, assistive robots that can adapt to a user's social preferences and interact with them in a natural way will allow for an overall positive interaction.

Section 3.5: Acceptance of Assisted Robots by Caregivers

End users will not be the only group interacting with AR. Caregivers, those in charge of overseeing care, will spend a significant time interacting with any implemented AR. The needs and wants of the caregivers need to be considered as well as that of primary users in order to create productive assistive robots. The criteria for caregiver acceptance can be divided into two main categories: general ability of a caregiver to accept the aid of an assistive robot and caregiver preference in their interaction with assistive robots (Pino, 2015).

Caregivers may resist new technology that may impact daily schedules. One caregiver who works at an assisted living center noted that the new technology "may be met with some resistance by members of the staff who have been doing things one way for a long time." Caregivers displayed a higher level of interest in socially assistive robots than the older adults with mild cognitive impairment surveyed but less than that shown by healthy older adults (Pino, 2015). The same study allowed caregivers the opportunity to rank their preferences in robot applications. Caregivers prioritized safety and health care for care recipients followed by compensation for cognitive impairment as their highest rated applications (Pino, 2015). Caregivers' lowest rated application was communication and social support. From this data, we can make a few conclusions about caregiver acceptance of assistive robots. First, caregivers will be more willing than primary users to integrate and interact with an assistive robot although the opinions of caregivers still tend to be more hesitant than healthy older adults. Second, caregivers will be more accepting of assistive robots if they focus primarily on the safety and health care of the care recipient.

Additional research has shown that 87.5% of caregivers believed that socially assistive robots could alleviate some of their day-to-day obligations (Pino, 2015). A caregiver interviewed said, “I do think there are certain jobs that are repetitive that could be better suited for robots than the staff working at the home.” However, a majority of the caregivers surveyed believed it would be presumptive to completely replace caregivers all together with assistive robotic technologies (Pino, 2015). They expressed fear for rushed designs and computer error that could potentially endanger the end user. In addition, caregivers expressed concern with robot autonomy in the home care setting (Beuscher, 2017). Many at home caregivers lack the technical expertise of professional caregivers. This requires a design catered towards inexperienced users who can easily exhibit control over the robot. Overall, caregivers desire robotic assistance in a limited and controlled capacity where they are present and have ultimate control (Beuscher, 2017).

Caregivers have shown to have different preferences in robot interaction than end users. Caregivers have shown more concern with the usability of an assistive robot rather than its design. Caregivers expressed concern for computer interfaces that they worried would be unusable by users with degenerative diseases such as dementia. A young assisted living center staff member explained, “It would also be pretty difficult to teach them how to interact with or use the robot considering most of the people I take care of have some sort of degenerative disease affecting their memory.” Additionally, hyper realistic human looking designs could confuse users with degenerative diseases (Wang, 2016). Caregivers expressed concern with the use of computer interfaces to communicate between the end user and robot. This type of design would be confusing for dementia patients as well as older users inexperienced with technology reasoned one caregiver (Pino, 2015). This caregiver pointed out that her husband, an older man with dementia, struggled using the telephone so any foreign technology would be practically impossible for him to adopt. The overall opinion of caregiver's shown in this study can be summarized by a desire for customization in user-robot interaction. Caregivers were keen to point out potential pitfalls or shortcomings of robot implementation including limitations in interface and appearance based on the condition of the end user (Pino, 2015). This means AR will need to be adaptable based on user and caregiver circumstance in order to be effectively adopted into society.

Though rated lowest among preferred skills, many caregivers expressed positivity when considering the social aspect of assistive robots. They noted the presence of a trusted assistive robot could induce feelings of comfort as well as reduce anxiety in users by providing answers to repetitive questions and providing a social presence (Wang, 2016). Caregivers are often limited by their schedules and have several clients they attend to. A user-specific AR would provide the constant source of social interaction that caregivers are often unable to give. Some caregivers even believe an AR will be able to provide greater assistance than themselves, especially for caregivers who are related to the user (Wang, 2016). These family caregivers noted the potential strains on their relationship with the user that occurs due to their role as caregiver. Asking an assistive robot for assistance may be seen as less burdensome than asking a caregiver for some users. However, not all caregiver respondents shared the same positive outlook on the social capabilities of assistive robots. Regarding the robot, one caregiver said, "It's a piece of machinery...just like your computer screen... it doesn't really make you responsive, emotional response, it's a piece of machinery." (Wang, 2016). Therefore, the social capabilities of AR may rely in part on the caregiver's willingness and acceptance of an assistive robot as a social tool rather than just a physical one.

Chapter 4: The Optimal Assistive Robot Design for Selected User Groups

Erika Dow, Vy Le, Esther Roselaar, Shulin Wang

Section 4.1: Introduction

As outlined in the previous chapters, users have preferential characteristics for integrative and interactive aspects of assistive robots. Beyond these integration and interaction considerations, characteristics and functionalities of the optimal AR have not yet been defined; therefore, a need exists to analyze and outline important factors to incorporate in AR for various user groups. There is not a fixed set of characteristics that can be universally applied to all user groups and optimally address their differing needs. Consequently, design factors will be assigned based on the following stakeholder groups: users who are aging or have physical disabilities, users receiving rehabilitation at home, and users with disabilities with educational needs. To strategically develop design considerations and preferences, considering all of these factors, a decision matrix was created for each stakeholder AR.

A decision matrix helps engineers compare and weigh design features between robots more objectively. Each matrix consists of multiple criteria regarding the various functions an AR could have. A weight score is assigned to each criteria to represent the importance of that criteria in the perspective of each stakeholder group (i.e. Aging-in-Place AR, Rehabilitation AR, Educational AR). These weights allow for comparison between different robots and how they satisfy the most important needs of stakeholders. In Table 4.1, significant information regarding pre-existing robots in the market are summarized, and will therefore be beneficial in determining their scores in the decision matrices (Tables 4.2-4). The higher the score, the more closely it is deemed to be optimal. Nevertheless, there are bound to be further improvements for every robot.

Table 4.1.1: Summary of pre-existing assistive robots that will be used as comparisons in the stakeholder-specific decision matrices below.			
Robot	Description	Cost	Photo
Jibo	Jibo is considered the world's first social robot for the home, and is designed as an interactive companion and helper to families.	$899	
Stevie	Stevie is a socially assistive robot that is designed to help users by engaging with them socially as well as physically.	$22,000 - $33,000	
KUKA LBR Med	KUKA LBR Med is designed to enhance mobilization of bedridden patients, so that they can gain a degree of mobility again.	$50,000 - $100,000	
Manus ARM	Manus Assistive Robotic Manipulator is an intelligent and precise wheelchair-mounted robotic arm that is controlled using a chin switch or other input device.	Quote required	

NAO	NAO is an interactive, intuitive, and friendly programmable personal teaching assistant that can be used to educate students.	$8,000 - $16,000	
BUDDY	BUDDY is a friendly, smart, and mobile robot for the home that is capable of connecting, entertaining, and educating users.	$1,700 - $2,000	

Section 4.2: Optimal Aging-in-Place Assistive Robots

Section 4.2.1: Introduction

Aging is a life phase that typically coincides with diminished motor, sensory, and/or cognitive functioning, making it an attractive area for the introduction of AR technologies. Because the user group is so large, investing in developing these technologies could have a significant impact on society (Goldberg & Saul, 2016). In designing the optimal AR for the aging population, one popular objective is to develop a robot that will allow users to remain in their homes, also known as aging-in-place, for as long as possible. Aging-in-place is preferable to most people for reasons of dignity, autonomy, and economics (Morley, 2012). Therefore, the optimal AR for the aging population would be an AR that allows users who are aging to maintain their independence even as their physical and/or mental capabilities decline (Table 4.2.1). Beyond the functional performance of AR, safety, cost, and other factors (described in previous chapters) must be considered, as they will all play a role in the acceptance and adoption of them.

Section 4.2.2: Functions of Assistive Robot

By assessing the reasons for which people tend to move to nursing homes or other long-term care institutions, the capabilities of the optimal AR for aging-in-place become clear. The article, *Aging in Place,* notes that “the major predictors of institutionalization are inability to use the toilet, balance problems, and dementia” (Morley, 2012, p. 489). A separate study concluded that the most significant risk factor for long-term nursing home placement (LTNHP) was age, specifically being over the age of 80 (Castora-Binkley, et al., 2014). This indicates that the natural physical and mental decline that people experience plays the largest role in their ability to maintain independence. These declines lead to limitations on peoples’ abilities to do activities of daily living (ADLs), which are specific functions that would be required of an AR to achieve prolonged aging-in-place. The same study found that higher educational status and higher risk of cardiovascular disease predicted LTNHP, neither of which can be impacted by an assistive robot (Castora-Binkley, et al., 2014). On the other hand, the study also identified factors that decreased the risk of LTNHP. They found that better cognition was the highest contributing factor in that aspect. Therefore, an AR that can aid users in maintaining their cognitive functions would be optimal for the aging population that wants to age-in-place. Additionally, people who may be the best candidates for AR technology, would be those with high enough cognitive abilities to learn how to use the AR effectively, allowing for these individuals to maintain their cognitive abilities for longer. This could be achieved in a multitude of different ways, but one way that cognitive functions are maintained within elderly populations are through the use of Socially Assistive Robots (SAR) (Čaić, et al., 2019).

Section 4.2.3: Cost

These assistive robots will only be as useful as they are adoptable, which means that they need to be both reliably safe and cost effective (Dahl & Boulos, 2014). To determine the range of reasonable costs associated with an assistive robot designed to allow aging users to age-in-place, an assessment of the current costs associated with LTNHP can be compared. The AR technology must then cost no more than the alternatives or a cost only marginally more with that margin being defined as the added value that the assistive robot brings to peoples' lives beyond what the alternatives (e.g. assisted living) offers. This margin of value will vary from person to person and is extremely difficult to quantify, so for the purposes of this paper, the optimal assistive robot will be considered equal to or less costly than assisted-living.

While it is common knowledge that care for aging individuals is always costly, the exact figures for how much different types of care cost are less simple. For example, costs for nursing homes vary greatly by location, even when only considering the United States. However, in order to define an optimal assistive robot that is relevant to the broadest number of people within the aging population, national healthcare averages will be used as measures of costs for caregiving. The median monthly cost for an assisted living facility in 2019 was $4,051 and the median monthly cost for a nursing home facility were $7,513 and $8,517 for a semi-private room and a private room, respectively ("Cost of Long Term Care by State: 2019 Cost of Care Report" , 2020). Living in a nursing home facility involves attendant care, which would not be replaced, but rather augmented by current AR technology. Therefore, the cost associated with an AR that allows users to avoid moving to an assisted living facility, which does not typically include attendant care services, must cost equivalent to or less than $4,051 per month. There are also other features associated with assisted living, such as accessible building design and close access to amenities (e.g. dining facilities, social events, etc.) that are mitigating factors. An article, specifically addressing the complexity of deciding between assisted living and aging in place, cited that “basic home modifications — including installing grab bars, sturdy handrails along stairs, replacement rugs, better lighting and lever-handled doorknobs — can cost up to $10,000 (Lynch, 2018),” indicating that aging in place is extremely costly. However, an AR could make some of those home modifications unnecessary, if the AR is able to assist or perform those tasks in a home that does not have those modifications. Likewise, aging in place provides alternative benefits, such as continuing to live in one’s community, proximity to family, and other factors (Lynch, 2018).

Table 4.2.1: Decision matrix for aging-in-place assistive robots. The “Weight” scores are determined by survey and interviews and depict the importance of each criterion according to the stakeholder. The scores listed under each robot is how well the robot satisfies that criteria. The higher the score, the more the robot is suited for this vocation.

	Aging in Place AR		
Criteria	Weight	Jibo	Stevie
Cost	4	5	2
Safety	5	4	4
Respond to particular disabilities	1	2	1
Detect and respond to sound stimuli	4	3	4
Have a variety of communication methods	2	2	5
Interpret gestures or movements	3	5	1
Provide feedback	5	5	5
Provide cognitive stimulation	5	5	5

Detect and respond to visual stimuli	4	3	1
Educate users	1	4	4
Track user's progress (physical and mental)	1	3	2
Provide physical assistance	5	1	3
Total		147	133

Section 4.3: Optimal Rehabilitation Assistive Robots

Section 4.3.1: Introduction

Rehabilitation involves restoring one's life back to health or normality through training and therapy. There are numerous reasons why someone may need to go through rehabilitation processes, including addiction, illness, imprisonment, or medical procedure. This review focuses upon the rehabilitation process and needs for patients who have undergone medical diagnosis or treatment. Rehabilitation requires a team, conventionally composed of a physiatrist, rehabilitation nurse, physical and occupational therapist, speech pathologist, rehabilitation psychologist, and case manager. The main focus of a rehabilitation nurse is to assist patients in recovering and regaining independence and functionality following an injury, disability, or illness. A rehab nurse will usually educate and assist patients to manage chronic illnesses and injuries (Writers, 2020). There is a promising future in using AR to help guide therapy, motivate, and track persons in their rehab process, in other words, performing the roles of rehab nurses in one's homes.

Section 4.3.2: Different Stages of Rehabilitation

There are four stages of rehabilitation, each composed of different goals and activities, hence requiring assistive robots to have different functionalities. Preventive rehabilitation (prehab) is a preventive risk management strategy that is designed to condition the body to heal quickly after a surgery, speed up the recovery process, or prevent injuries from occurring. Prehab therefore requires more educational assistance than physical assistance since patients are assumed to still be in their healthy state and can help themselves. Restorative rehabilitation is therapy that is designed to improve one's mobility, including walking, repositioning, standing, sitting, and transferring from one place to another. This type of therapy will require physical help, specifically one that provides support for weight shifts. Supportive rehabilitation consists of care coordination services to be provided at the patient's home. These services are typically for those coming home from a rehab setting, those aging at home, or those with disabilities wishing to live independently. Unlike the past two types of rehabilitation therapy, support rehabilitation can require more than one type of assistance; social, educational, and physical assistance will have to be provided. Finally, palliative rehabilitation refers to the medical caregiving approach aimed to optimize the quality of life and reduce suffering among people with serious and complex illnesses. This mostly requires monitoring services; there is a need to track physiological conditions, detect particular symptoms, and sense psychosocial distress.

Section 4.3.3: Tracking of Rehabilitation Process

In Table 4.3.1 optimal rehabilitation robots are specially designed to provide physical or mental support to a patient undergoing one or more of the four stages of rehabilitation. More specifically, rehabilitation robots should be able to recognize symptoms or facilitate the recovery process. This capability of expediting the recovery process is often associated with the ability to recognize and keep track of a patient's condition. The tracking function is essential because it allows healthcare providers to adjust treatment plans as needed and maintain patient engagement. Upon the beginning of a treatment, a patient should be periodically tracked and reassessed. If a patient is not reaching desired treatment goals, this ongoing treatment shall be modified. This is called a treatment to target, measurement-based care approach that is commonly used in mental health conditions and chronic medical conditions. As previously reported, periodically tracking the effectiveness and progress of a treatment results in a higher chance of positive changes to health management (Banasiak, et al., 2020). To make this tracking more objective, a quantitative measurement should be developed. Because the end goal of rehabilitation robots is to help patients resume to normal life as much as possible, one possible measurement could be the rate of function restoration of patients. The use of Glasgow Coma Scale (GCS) is an example routine neurological scale that provides an objective method of rating the state of an individual's consciousness (Writers, 2020). GCS is routinely assessed in persons that have sustained some type of brain injury over a period of time. An increase of GCS is a strong indication of the progression of a neurological condition or effectiveness of a given treatment.

Section 4.3.4: Cost and Safety

To promote the usage of assistive robots, it only makes sense when the cost associated with assistive robots is equal or lower than that of the conventional care. According to a physician at the Rehabilitation Hospital of Indiana (RHI), cost is one of the major reasons why patients do not continue physical rehabilitation. Hence, cost is an important factor to take into consideration. A $50,000 assistive robot that could be amortized over a three-year period could be equivalent to hiring a therapist for several hours per day for the same time period (Tabaj, 2012). On top of the cost of purchasing robots, other costs including installation, customization, and maintenance should all be considered. Another important factor affecting decision making is safety. When asked about safety related issues, the RHI physician commented that most of their patients have undergone a significant amount of suffering prior to rehabilitation, and thus, extra care is needed to keep them safe. The integrity of patients' safety in both physical and cognitive aspects should be regarded as a mandate. For example, for a patient with cognitive deficiency, after using a robot, the condition should not get worse purely due to the usage of robots.

Table 4.3.1: Decision matrix for rehabilitation assistive robots. The "Weight" scores are determined by survey and interviews, and depict the importance of each criteria according to the stakeholder. The scores listed under each robot is how well the robot satisfies that criteria. The higher the score, the more the robot is suited for this vocation.

	Rehabilitation AR		
Criteria	Weight	KUKA LBR Med	Manus ARM
Cost	4	1	2
Safety	5	4	5
Respond to particular disabilities	3	4	5
Detect and respond to sound stimuli	3	2	1
Have a variety of communication methods	1	1	2
Interpret gestures or movements	5	2	4
Provide feedback	4	1	2
Provide cognitive stimulation	3	1	1
Detect and respond to visual stimuli	4	1	2
Educate users	2	1	1

Track user's progress (physical and mental)	5	4	1
Provide physical assistance	5	4	4
Total		106	119

Section 4.4: Optimal Educational Assistive Robots

Section 4.4.1: Introduction

Users with educational needs comprise a large segment of the population that would benefit from an AR (“Children and Youth with Disabilities”, 2019) To meet educational needs, a robot may need to interact with a variety of students and fit into a typical classroom setting. Other considerations lay in how assistive robots may supplement traditional educations in addition to cost and safety requirements that would make such an AR feasible (Table 4.4.1).

Section 4.4.2: Functionalities for different types of students

The optimal assistive robot would be able to adapt to the needs of different students. This involves the ability to work with students in a range of academic capabilities as well as accommodate and assist those with learning disabilities. A robotic lecturer named Yuki, introduced in Germany in 2019, was able to understand how the students were doing academically and provided the necessary support. Many students had “found Yuki useful” even though vast improvements still need to be made to the system. Yuki also assisted in the classroom by proctoring exams and providing timely grading of assignments. By performing these tasks, an instructor will have more time to dedicate to fulfilling the learning needs of students (“Professor Robot – why AI could soon be teaching in university classrooms”, 2019). Features necessary to an assistive robot in performing such tasks may include a camera for proctoring or even scanning paper assignments, and the ability to communicate with a third party for data and assignments necessary for grading.

Communication needs may also vary between students. Vision and hearing impairments or language-based learning disabilities create the need for a robot that is able to communicate in a variety of ways. To accommodate the range in communication types, the robot should have text-to-speech, speech-to-text, word prediction, and graphic organizers. The ability to communicate in many ways will most likely require an interactive screen, the ability to detect and translate speech, and vocalization capabilities (Young & Maccormack, 2014).

Different learning styles are sometimes required so must be considered when designing the optimal robot for educational needs. One of the more common forms of teaching is by lecturing, which a robot can perform by reading from a transcript or voicing a recording, achieved with the communication features listed above. Alternatively, some students learn best from teaching others. A study conducted at the University of Tsukaba found that implementing care-receiving robots in a classroom improved the students' ability to recall English verbs both the day of the experiment and 3-5 weeks later. The robot was programmed to occasionally answer wrong so the student would have to correct the robot. The study also noted that students generally taught the robot through three methods: direct teaching (ie. taking the robot by the hand and leading it through steps), gesturing, and verbal teaching (Tanaka & Matsuzoe, 2012). The ability to assist with the care-receiving learning style would require the robot to have some sort of movable arm for those learning through direct teaching, the ability to interpret gestures, and the ability to detect and interpret speech. Furthermore, the robot must decide when to answer incorrectly to allow the students the opportunity to learn through correction.

Section 4.4.3: Supplement traditional education and integration into the classroom

Assistive teaching robots likely will not entirely replace in-class instructors so the robots must cohesively supplement traditional education. A study in South Korea found that it would not be beneficial to remove instructors altogether as students still respond with “greater social attraction” to instructors than to robots; however, the robot was perceived with comparable results to the instructor when positive feedback was provided to students. When neutral or negative feedback was given to students, the instructor was received significantly better than the robot. The robot in the study was expressionless and lacked gestures possibly explaining why the instructor was preferred when neutral or negative feedback was delivered. This study demonstrates that an educational robot is best received and integrated into the classroom when it provides positive feedback to the learner; furthermore, the ability to convey feedback with expressions and gestures may also be beneficial (Park et al., 2011). To provide the necessary feedback complete with expressions and gestures, the robot should have a somewhat humanoid face capable of making expressions as well as some sort of arm or hand for gesturing.

Language barriers between student and teacher present another hurdle in delivering a complete education (personal communication, April 10, 2020). Though assistive teaching robots may not replace in-class instructors, an AR providing live translation between student and teacher would increase the teacher’s ability to convey concepts verbally (personal communication, April 10, 2020).

Section 4.4.4: Cost and Safety

Wheeled robots occupy the largest market category within the educational robot market, comprising 56% of the total market share. Wheeled robots are typically found in elementary schools due to their ability to engage children and the demand for such robots is expected to grow. Furthermore, development of manufacturing technology, cheap raw materials, and competition are leading to a 2% price erosion. Government initiatives are able to provide some funding for bringing teaching robots to the classroom (“Educational Robots Market Size, Share, Trends, Opportunities & Forecast”, 2019). As education funding cuts become increasingly common, teachers might turn to grants to afford the addition of an assistive robot for the classroom. Another source of funding occasionally comes from companies willing to work alongside classrooms in return for product promotion (personal communication, April 2, 2020).

As educational assistive robots will most likely reside in classrooms, safety is of the utmost importance. Sharp edges should be avoided in robot design while tamper-protection needs be considered. Further safety consideration needs to be taken if the AR has movement capabilities as the robot must have a heightened awareness of its surroundings to avoid contact with students or breakable objects (personal communication, April 2, 2020).

Table 4.4.1: Decision matrix for educational purposes assistive robots. The “Weight” scores are determined by survey and interviews, and depict the importance of each criteria according to the stakeholder. The scores listed under each robot is how well the robot satisfies that criteria. The higher the score, the more the robot is suited for this vocation.

	Education AR		
Criteria	Weight	NAO	BUDDY
Cost	2	3	4
Safety	3	5	5
Respond to particular disabilities	3	3	3

Detect and respond to sound stimuli	4	4	4
Have a variety of communication methods	5	2	4
Interpret gestures or movements	4	4	4
Provide feedback	5	4	3
Provide cognitive stimulation	1	4	5
Detect and respond to visual stimuli	2	5	5
Educate users	5	5	5
Track user's progress (physical and mental)	2	2	3
Provide physical assistance	1	2	1
Total		137	146

Section 4.5: Conclusion

AR was analyzed in both conceptual (through analysis of design features) and concrete (through analysis of existing ARs) ways with respect to each of the three user groups: those aging and developing physical limitations, those receiving physical rehabilitation at home, and those with disabilities requiring educational needs. Results from analysis through literature reviews, decision matrices, interviews, and surveys, concluded that the conceptualized optimal AR for each specific user group has yet to be brought to the market. However, there are already a number of well-developed alternatives that are already developed. As shown through the decision matrices, several existing ARs are more or less optimal overall. They each also have strengths and weaknesses, which are weighted according to the evidence collected. However, these weights differ across stakeholders as different groups were found to have different criteria prioritization in what is considered to be the optimal AR. The results and recommendations based on this research was established in an effort to provide generalized conclusions, but it is worthy of recognition that individual preferences may differ or conflict.

For users who are intending to age in place, one of the most important features was determined to be aiding in maintenance of cognitive functioning. This design characteristic could be implemented in a variety of different ways, such as how they have been implemented through the SARs Jibo and Stevie. Additionally, the capability to aid in the completion of ADLs is a critical design feature for ARs designed for the aging population. Another design feature that is of high importance to this user group is that the AR is able to detect and respond to visual stimuli, which was a large contributor to Jibo being more optimal than Stevie.

For users undergoing rehabilitation, progress-tracking was identified to be the most significant factor that ARs should have. The recording of progress made by an individual experiencing the process of rehabilitation is essential to the individual in several ways. Not only are they able to receive confirmation that progress is being made, which is an effective method of mental motivation, but also obtain information on how their process can be better. In comparing existing ARs for rehabilitation needs using weights that were deduced by literature review and interviews, it was discovered that the Manus ARM was generally better than the KUKA LBR Med. However, the Manus ARM can be further made optimal if it includes a progress-tracking feature. Research on important criteria also revealed that safety and the ability to interpret physical motion were significant.

For users with disabilities with educational needs, communication was determined to be one of the most important design considerations. As learning styles differ between students, ARs must be able to deliver concepts in auditory and visual manners, utilizing gestures, inflection, and feedback in their communication. The educational AR BUDDY has a greater variety of communication methods than the education AR NAO. BUDDY also is better able to track the student’s mental progress. These two criteria became the critical factors in determining that the educational AR BUDDY would be better suited to serving users with disabilities with educational needs. Other criteria that were found to be important in educational AR were the ability to provide feedback to students and safety.

Chapter 5: Impact of Assistive Robotics on Persons with Disabilities and the Aging Population

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Section 5.1: Introduction

This chapter explores the future impact of assistive robotics (AR) on economics, health and well-being, and independence of people with disabilities (PWD), older adults above the age of 65 years old, and their caregivers. AR is anticipated to provide significant benefits for PWD and older adults (Hersh, 2018). In some instances, AR will enable PWD and older adults to live more independently and reduce their reliance on caregivers. This technology will also decrease the long term investment costs and spending on formal caregivers, such as nursing assistants, or on assisted living. AR would also enable some individuals to continue participating in the labor force, increasing their disposable income and locus of control, or afford them better access to educational and rehabilitation services, improving self-perception and physical health. AR could also aid caregivers, often family members, who support and provide services to PWD and older adults. Informal caregivers, such as friends and family, are often overburdened with raising children, working, and caring for their elderly parents. These informal caregivers would have the opportunity to remain employed while affording them to focus on their relationships with friends and family who are experiencing aging or who have a disability rather than day-to-day caregiving tasks. This technology would likely improve the mental and physical health of caregivers by alleviating stress.

Section 5.2: Long-Term Economic Impacts of Assistive Robotics

Section 5.2.1: Impact of Assistive Robotics on Personal Finances and Employment

AR designed for the workplace may help users' personal finances by helping them remain employed. AR has also been designed for use by PWD in the workplace. For example, assistants like Alexa are used to help remind PWD of tasks both at home and in the workplace. At present, the average household in which the primary breadwinner does not have a disability has a mean annual income of $73,874 (Sonik, et al., 2018). If the primary breadwinner of the household has a non-severe disability (as defined by the US Department of the Census), average household income is about $9,000 dollars lower, at about $64,762 dollars annual income (Sonik, et al., 2018). Households in which the primary breadwinner had a severe disability had a mean annual income of only $46,300 dollars (Sonik, et al., 2018). This is largely because PWD often work low-paying jobs, relative to persons without disabilities.

PWD are also far more likely to be unemployed. Among American parents, 80.8% of parents without a disability are employed, while only 35.1% of parents with severe disabilities are employed and working (Sonik, et al., 2018). As a consequence, an estimated 30% of parents with disabilities live below the US federal poverty line (Sonik, et al., 2018). A positive correlation was found to exist between a parent with a disability being unemployed and that parent not being able to see a doctor when necessary, missing rent or mortgage payments, and/or having utilities turned off for missed payments (Sonik, et al., 2018).

The American federal government provides various programs intended to financially assist PWD who are unemployed or whose wages do not suffice to cover household needs. However, despite the fact that parents with disabilities are more likely to rely on government assistance programs, even those who receive benefits from agencies and programs such as the

Supplemental Nutrition Assistance Program (SNAP) and Supplemental Security Income (SSI) were still found to live with a higher level of material hardship (Sonik, et al., 2018). Governmental benefit programs do not adequately address the issue of poverty in households where one or more adult partners have a disability.

It would be highly preferential for any household with disabilities to have one or both adult partners bringing in sufficient income to stay above the federal poverty level, for the sake of household finances, health, and living standards, as well as the personal fulfillment derived from employment. According to the US Bureau of Labor Statistics, in 2016, about 12.7% of Americans lived below the poverty level, but only 4.9% of employed Americans lived below the poverty level (A profile of the working poor, 2016). This is to suggest that, if one or more partners in a household with disabilities was employed at least part time, their chances of living below the poverty level would decrease by more than half.

AR would also have the potential to enable older adults to continue working if they are inclined. Many older adults have decided to work part-time or donate their time babysitting grandchildren or helping charitable organizations. Countries with large aging populations would benefit the most from keeping people working, even if part-time, for as long as possible. Japan has one of the largest aging populations with approximately 40 percent of its population over age 55 (CIA, 2018). As this population ages, there are fewer workers in younger generations to take their place. Approximately 41.4 % of those that left the labor force in Japan in 2012 left due to illness or old age, not because they have the means or desire to stop working. Another 3.5% also left the workforce to provide care for others (Matsukura, et al., 2018, 238).

Japan currently represents the demographics of many industrial nations in future years. The United States, for example, has approximately 30% of the population over age 55 (CIA, 2018). By 2050, over 21% of the population of the United States will be over age 65 (U.S. Census Bureau, 2014). Robotics and automation in the workplace will continue to help the global economy by allowing older adults to produce more with less effort and allowing nations to maintain economic output with a smaller workforce.

Section 5.2.2: Impact of Assistive Robotics on Caregiving Costs

An important point to stress in terms of household finances is the role of caregivers. When partners, parents, or children of PWD spend their time performing caregiving tasks, the caregivers lose potential working hours. That loss of time can represent lost wages (which might have helped the household to stay above the federal poverty line), pay bills, and afford medical care. The overwhelming majority (75.4%) of caregivers of wounded American veterans, for example, were employed before becoming caregivers (Christensen, et al., 2012). About 40.6% of these caregivers spent less than 10 hours a week, by their own estimate, on caregiving tasks, which likely still allowed them to work, but 26.9% of these caregivers spent more than 40 hours a week on caregiving tasks, which may inhibit these caregivers from holding any employment (Christensen, et al., 2012). Although they represent a small segment of the caregiving population, caregivers of veterans are a good sample group to compare with national populations because of the diverse types of disabilities that veterans have. About 40% of wounded veterans having one or more amputated limbs, about 30% of wounded veterans living with traumatic brain injury, and about 10% of wounded veterans being either fully or partially blind (Christensen, et al., 2012).

If there is a way for PWD to afford AR that can perform one or more caregiving tasks, the primary caregivers can work longer hours or even rejoin the workforce. It is important to emphasize here that, unless they receive some assistance (either from private insurance or government programs), it is unlikely that PWD and their families who already live at or near the poverty line would be able to purchase an expensive robot and receive these potential financial benefits. However, if AR are be made accessible to the households of PWD, at the current federal minimum wage, freeing up just one caregiving hour a day for paid employment would earn approximately $36.25 per laborer per week or, in macroeconomic terms, over $2.4 billion earnable for the 65.8 million informal caregivers in the US per week (Schulz, et al., 2010). As stated in an interview with an American veteran, who is a double leg amputee, “long term the robot may be the more cost effective option” depending on features and ability to perform caregiving tasks.

AR can improve the mental and physical health of caregivers and families by redistributing or reducing caregiver responsibilities. Caregiver stress is a unique mental health problem defined as distress caused by an unequal sharing of caregiving tasks between people. This is only expected to worsen in countries with a labor market shortage. Although the number of available caregiver jobs is expected to increase within the next decade, a shrinking workforce, aging population, financial pressures, increased consumer demand, family fragmentation, and bureaucratization of long-term care will prevent these positions from filling (Fleming, 2003, p. 1028). This will not only cause professional care for older adults and PWD to be even more expensive, but also create additional stress for future formal and informal caregivers.

Currently, there are an estimated 15 million informal caregivers in the US caring for people with Alzheimer’s disease (AD) alone. According to Fleming, “The most commonly reported problems by the caregivers were loss of free time, conflicts regarding responsibility for patient care among relatives, loneliness, a loss of social relations and a high rate of absenteeism from work…” (Fleming, 2003, p. 1028). The implications of lost working hours on personal finances and national economies has previously been discussed, but it is also important to recall the emotional consequences of lost work and their relevance to caregiver health. For many of these caregivers, work provides (or provided) a sense of security about their family’s well being, a feeling of personal accomplishment, and even a sense of identity. This sense of identity, security, and happiness is further damaged by the loss of social relationships, connections which are important to the regulation of stress. Stress was significantly higher in AD caregivers, regardless of severity of AD, than non-AD caregivers. Somatization, depression, hostility and psychoticism scores were also higher in caregivers of AD patients as a whole than in caregivers of the non-AD group (Fleming, 2003, p. 1028).

Informal elder-care has many unappreciated indirect costs - most notably the time sacrificed by caregivers who often cut back their hours of paid labor to perform caregiving tasks. There are about 34 million informal caregivers of older adults and PWD in the United States (approximately 10% of the total U.S. population), as opposed to 4.4 million paid caregivers. Even families which use paid caregivers often use a combination of formal care (during the at-home nurse's shift, etc) and informal care (care by family members after hours). Paid caregivers make approximately $30,000 a year according to Glassdoor (Glassdoor, 2020). AR would free up this time and income to be spent elsewhere instead of on caregiving and its associated costs.

Section 5.3: Long-Term Impacts of Assistive Robotics on Societal Health and Well-Being

Section 5.3.1: Impact of Assistive Robotics on At-Home Rehabilitation

AR can also help older adults and PWD improve their physical health and encourage rehabilitation. Much of the attention in rehabilitation robotics has been devoted to assisting the survivors of stroke in learning how to recover mobility in their limbs and fine motor control in the hands. Neural tissue damage as a result of stroke may cause hemiparesis or hemiplegia and it may cause loss of mobility from the shoulder to fingers in up to 80% of stroke patients (Arya et al, 2018). As a consequence of hemiparesis or hemiplegia, many people who lived independently and had full range of motion before a stroke are no longer able to live independently and require assistance with 1 or more activities of daily living (ADLs) after a stroke (Arya, et al., 2018). Mobility and fine motor control in the hands have a higher correlation with ability to complete ADLs, although ADLs often depend on complex cognitive functions in combination with fine motor skills (Paula, et al., 2016).

However, rehabilitation whose goal is the recovery of motion in the hands is among the least successful forms of post-stroke rehabilitation. As a consequence, an entire field of rehabilitation robotics has arisen to address challenges of fine motor control in the hands.

Some prototypes, like the MIT-Manus robot, focus on coaching people through rehabilitation exercises for the hands (Emerson, et al., 2017, pp. 1-6). In the same vein of research is the Mirror Image Movement Enabler (MIME), which specializes in bilateral exercises for people who have only one paretic hand (Emerson, et al., 2017, pp. 1-6). These robots are currently intended as a supplement to traditional physical therapy for post-stroke patients, not as a replacement. The designers envision them as a kind of at-home practice tool, which could lead to faster recovery times. Practicing at home may also give people recovering from strokes a sense of control over their own recovery that can be reassuring, especially if those people have experienced a recent temporary or permanent loss of full or partial autonomy.

Importantly, not all hand motion rehabilitation robots share the same goal. Certain prototypes, such as hand exoskeletons, aim to change the role of the therapist from someone who practices exercises with a client using repeated, physical manipulation of a person’s hands to someone who prescribes appropriate exercises and directs the robot to complete them. These exoskeletons may improve the experience of the user during therapy. Since the most current exoskeletons are directed by the EMG signals of the user, it can manipulate the position of a person’s hands during the exercises at a rate and to an extent which is comfortable for the user (Akgun, et al., 2019). This is to be distinguished from a previous class of hand exoskeletons, which aim to replace neurologically-directed mobility in the hand with hand mobility directed by electrical impulses of the device, which is itself controlled by the user (Akgun, et al., 2019).

Less attention has been paid to the experiences of people with dementia who use the same AR (such as Manus and MIME) in similar therapeutic environments (Emerson, et al., 2017, pp. 1-6). The goals of these users would be different from the goals of users who are recovering from stroke, in that people with dementia seek to prolong for as many months or years as possible the fine motor control that they already have. However, the fact that these AR are being used “off-label,” so to speak, in a clinical setting for which they were not originally designed, testifies to the ability of AR to move into unforeseen markets once a product becomes available. A rehabilitation specialist in equine assisted therapy, for example, saw the usefulness of AR in a unique light. She explained, “A robot horse would enable riders to build core strength in situations when they can’t ride a real horse,” and further explained how robots mimicking the motion would allow PWD to gain confidence before experiencing therapy with a real horse (S. McGow-Russell, personal communication, April 23, 2020). AR which incorporate machine learning are designed to adapt to the user, and although no given product has infinite adaptive abilities, that adaptive quality can make them broadly useful.

This shift in the goals and priorities of exoskeleton design reflects an increasing confidence in the ability of people to recover substantial amounts of mobility and autonomy after a stroke. It also reflects a shift in perspective that prioritizes the user’s own experience of using the robot, in tandem with the goal of recovery. The user is encouraged to be proactive and engaged with the AR that he or she is using. This increased level of engagement and sense of respect for the user as an active, not passive, part of the therapy may make users more likely to adopt AR in post-stroke recovery (Emerson, et al., 2017, pp. 1-6).

Section 5.3.2: Impact of Assistive Robotics on Spread of Disease

Another unanticipated impact of AR is preventing the spread of disease by using robotic caregivers instead of human caregivers when human caregiving is dangerous. Human interaction allows most diseases to spread from person-to-person (CDC, 2016). Older adults are a large at-risk population that can easily contract disease. An example of when this would help aging populations is the 2020 global pandemic of COVID-19, which is disproportionately affecting nursing homes around the globe. AR that can provide social interaction or accomplish some tasks of biological caregivers have multiple advantages. AR can be disinfected with more potent cleaning chemicals than hand soap or sanitizer, and AR can be disinfected with UV light or other forms of radiation. Also unlike human caretakers, they do not need to leave the facilities in which the AR are stored and used and are therefore unlikely to carry pathogens from another home, office building, or public space.

To inhibit the spread of infectious disease, specific AR has been designed and tested to teach children hygiene habits, such as hand washing. One such AR device is a “smart sink” which was installed in elementary school bathrooms to verbally remind children to wash their hands (Deshmukh et al, 2019). The researchers observed a 40% increase in the frequency of handwashing among elementary school age children who were verbally reminded to wash their hands (Deshmukh et al, 2019). Although this AR was not designed specifically for PWD, it could be useful for people affected by memory loss, such as people with Alzheimer’s or dementia. In a setting such as a nursing home, where many residents have trouble remembering daily tasks and where disease transmission is common, it is possible that “smart sinks” may reduce disease transmission by similarly improving handwashing behavior, although this remains to be tested.

Section 5.3.3: Impact of Assistive Robotics on Education

AR can help children and young adults with disabilities by enabling them to have greater academic and career success much later in life. Behavioral development with the robot is comparable to social interaction with living beings. In one study, AR used in the classroom improved social interaction among younger children. The study found that “most of the children interacted positively with the robot, exhibited heightened attention, performed motor and cognitive tasks, and reported a high degree of enjoyment of the interaction” (Friden, 2014, p. 262). This was confirmed anecdotally by a special education teacher who said students would be “drawn to” AR because mechanical objects spark interest in young children (personal communication, April 20, 2020).

Though the children in this study did not have disabilities, the research has implications about the potential use of socially AR for children with disabilities. For children with disabilities who are extroverted, AR can aid in the social and cognitive development in the classroom and indirectly impact educational outcomes. In another pilot study, the use of socially AR has been well received and shown to help autistic students remain in the mainstream classroom for a greater amount of time per day. These AR were shown to support classroom aids and special education teachers by removing some of their workload and redistributing tasks (Broadbent, et al., 2018, p. 295). A special education teacher, when interviewed, expressed that AR will help students in two ways. She explained “the more exposure they have to computers, [the more] kids will develop technology skills,” which she believed was vitally important to the future career success of her students (personal communication, April 20, 2020).

Not everyone may gain from the experience of interacting with a robot. The same study also found that “a relationship was observed between children’s poor social skills and their refusal to participate in interaction with the robot” (Friden, 2014, p. 262). This suggests that children who already have strong social skills are open to interaction with AR, but children with poor social skills are nervous or shy about AR interaction. One way that researchers tried to encourage children with poor social skills to interact with the robot was by changing the environment in which the interactions took place. When a child was asked to interact one-on-one with the AR, the child tended to interact with the robot less and for a shorter period of time. When many children were introduced to AR together, each child in the room had more interactions with the AR, and those interactions lasted for a longer period of time (Friden, 2014, p. 262).

The results of this study may suggest that using AR in a one-on-one therapeutic session, during occupational therapy, for example, might not be helpful for improving the social skills of children with disabilities. However, in this study, children were only asked to interact with the AR on one or two occasions. It may be worth investigating if children would overcome an initial shyness about the AR and interact with it progressively more over time. Still, this study does indicate that even children with poor social skills interacted with the AR more and for longer periods of time when other children were present. This suggests that AR could be useful in building the social skills of children with disabilities in group settings such as a classroom or a play group (Friden, 2014, p. 262).

Section 5.4: Long-Term Impacts of Assistive Robotics on Independence

Section 5.4.1: Impacts of Assistive Robotics on Aging in Place

The ability to live independently is cited as the most common response among seniors who opt to use AR in their homes. In an effort to continue to live independently, many seniors have purchased assistive technology such as Life Alert™ emergency calling pendants, hearing aids, and electric lift chairs (Majumder, et al., 2017). Other significant considerations included a desire to “stay safe”, need for personal contact, and additional entertainment outlets. The general attitude of older adults and PWD towards assistive technology is that it can help them regain some autonomy (Woods, 2020). However, would AR, a subclass of assistive technology, be viewed as favorable since it could help users to complete tasks that they can no longer manage themselves. Pilot studies in Singapore showed that when older adults were comfortable using “smart” technology in their homes, such as home monitors and fall detection sensors, it helped them maintain independent living for a longer period of time, which was preferred by most retired people (Woods, 2020).

For adults with mental and developmental disabilities, “A number of PIDD (people with intellectual disabilities) have difficulty retaining information, so technological aids that supply knowledge in an easily digestible form will be of immense use” (O’Brolcháin, 2018, p. 4). Assistive technologies (apps with limited AI) have helped children with disabilities gain autonomy while taking public transportation (Flores, et al., 2018, p. 495). A need exists for more research to indicate other potential benefits of AR use for people with mental and developmental disabilities.

Section 5.4.2: Impact of Assistive Robotics on Technological Reliance

Some research has suggested that AR may cause people to be over reliant on technology and that the information supplied to them may not be accurate. A study in the U.S. among children with disabilities discovered that “electronic ATs (i.e., apps on mobile devices) might distort or misrepresent information being made available for users” (O’Brolcháin, 2018, p. 5). Inaccurate information or manipulated information may be dangerous to personal welfare. For example, if an AR was supposed to inform the user that their stove was on, but it did not because of a malicious programming error, it would be a safety hazard. Reliance on any safety technology carries similar risks. If a blind-spot sensor on a car fails to pick up another vehicle in the blindspot of a car, and the driver chooses to rely on that instead of looking over their shoulder, there might be a collision. Though there is much excitement about the potential of AR for older adults and PWD, these populations may also be at risk of losing autonomy long term if they unquestioningly rely upon this technology.

Section 5.5: Conclusion

This paper discusses some of the broad, long-term impacts of AR on economics, societal health and well-being, and independence. Based on research and interviews conducted, there is reason to believe that AR will have an overall positive impact on PWD, older adults, and caregivers.

However, many consequences of human-AR interaction remain unstudied or results remain unclear. Caretaking AR may be able to more effectively support parents with disabilities while maintaining their careers, but this remains an optimistic speculation . It also remains unclear whether interaction with social AR will lead to the development of social skills in PWD. Relatively little research exists about the benefits of AR for people with mental disabilities and disorders, including conditions such as anxiety and depression. It is often presumed that using AR will improve mental health by alleviating the stress of difficult tasks, but this assumption needs to be substantiated.

Future exploration in this area also includes the impact of AR on consumer-centric healthcare for PWD and older adults. Although briefly discussed in the report, AR may provide increased access to healthcare that is personalized for an individual. Potential areas for discussion include AR in telehealth, medication dispensers, and surgical procedures.

More subject matter experts will need to be interviewed in the future as well. Although the primary focus for this paper was people with disabilities and caregivers, more interviews are needed with researchers and industry representatives who are at the forefront of AR. These individuals can provide the greatest insight into future technological advancement as they are constantly developing and interacting with AR and conduct focus groups in certain areas, such as advanced sensing integration, machine operation, and embedded computer technology. This may have larger implications not only for PWD and older adults, but for all AR users.

Recommendations

- Research and development should continue to be allocated to the study of AR because there may be tremendous impacts for a large part of the population including the aging population, adults with disabilities, rehabilitation outpatients, and children with disabilities.
- AR may initially be most beneficial when utilized within specific environments such as classrooms, the home, and nursing homes.
- AR may be especially beneficial to those in rural areas who need at home rehabilitation and are not in close proximity to rehabilitation centers.
- Greater research and development of ARs is needed and should be performed in order to make AR less expensive and more accessible.
- The most successful user control interfaces should prioritize safety, simplicity, and responsiveness.
- User interfaces must be designed for users with low technological experience, such as through the use of voice control, joystick, and/or easy-to-understand touch/button selections.
- Enabling the user to provide feedback that the robot can learn from will be helpful in providing more effective user-robot training.
- Robots need to automatically adjust to the safety needs and user preferences of each user without computer programming by the user.

- Successful integration of an AR within the home is dependent upon the user's willingness to proactively utilize the robot.
- ARs could be utilized in long-term care facilities to augment an experienced nursing staff and maintain more continuity within the daily routine.
- Group interactions with an AR in a long-term care facility can improve sociability between residents and boost overall morale.
- AR can assist caregivers in performing simple everyday tasks and when they are unavailable during off-hours.
- The robot should be flexible and adapt themselves depending on user preferences and needs.
- A successful AR should allow a user or their caregivers opportunities for more exposure and longer training times, as well as provide them with a fail-safe option at the user's discretion.
- Modularity in design tasks allow for greater customization for specific stakeholders and promote optimized interaction.
- User privacy is a priority and includes mechanisms to turn the device off, commands to keep the AR at the docking station, and what data to be collected
- The visual appearance of the AR should not fall within the "uncanny valley" of humanoid appearance
- Social interaction and communication of the AR with the user should have human characteristics.

- AR would be used to supplement caregiving allowing caregivers the ability to overrule or override AR actions
- For elderly adults living alone, socialization with AR may help decrease cognitive decline.
- For rapid adoption, AR must be of equal or lesser monetary value as compared to standard options of human caregiving.
- For patients undergoing rehabilitation, AR should be able to identify rehabilitation stages for individuals and track their progress.
- AR should have multimodal communication capabilities with audio and visual feedback using gestures and inflection in any chosen language.
- In order to convey visual lessons and information, educational AR should have a visual display as well as audio feedback.
- Educational AR should be capable of being customized for doing specific classroom tasks and recognizing students' performance.
- Assistive robotics can reduce the costs that some users spend on formal and informal caregivers.
- Assistive robotics can improve the quality of rehabilitation services by allowing some users to perform rehabilitation exercises without a therapist present and at home.
- Assistive robotics can assist in the health and well-being of users by increasing access to health services, increase access to education for some users, improve caregiver well-being by taking on a number of caregiving tasks and responsibilities, and promote user independence by decreasing reliance on formal and informal caregivers.

Methodology

Overview:

Due to the vast and emerging topic of assistive technology, we needed to study all areas of assistive robotics including the research, development, design, integration, and interaction. It was found that there were three groups of people that would be most greatly affected by the introduction of assistive technology. First, the aging population would be considered as the largest group of potential primary users. Secondly, students with cognitive and physical disabilities would be considered as another group of potential primary users. Alternatively, caregivers and family members of the primary users are considered to be imperative to the successful adoption of assistive technology. Therefore, the focus was placed on these three groupings of people throughout the duration of the study.

Literature Review:

A comprehensive literature review was completed using peer reviewed journals and summary (lay) articles. For a comprehensive list of articles referenced throughout the study, see the bibliography section.

Interviews:

Interviews were conducted via telephone, email, video call, and in person. These interviews included: educational professionals, people considered to be a part of the aging population, veterans with disabilities, and school resource counselors. For a list of interview questions, please see the appendix. We would like to extend a thank you to all participants of the interview process.

Survey Methods:

A survey was conducted through the use of Qualtrics, a web-based survey creation, through the use of Purdue University's Information Technology Department. The survey consisted of 23 questions that gathered information about background and perspectives of assistive robotics of the survey takers. Information, such as data and graphs, from the survey were calculated by qualtrics and were analyzed by the research team. This survey was distributed through Facebook groups, such as Autism Quality of Life, Caring for the Caregiver while Caring for your Aging Parents, Spinal Cord Injury support groups, Alzheimer's and Dementia, etc. Surveys were also sent to nursing homes for feedback. Results were received from a total of 6 participants ranging from ages 18 to 74.

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Appendices

A.1 Interview Questions

A.1.1 Interview Questions for Chapter 1

General Questions:

1. What is your career background?
2. What is your experience with children, the aging population, or rehab patients?
3. What is your experience with assistive technology or assistive robots? (Anything from Alexa and Roomba to socially assistive robots and caretaking robots)

   Definition of assistive technology: Any item, system, or product used to improve the functional capabilities of people with disabilities. Assistive technology can be bought off-the-shelf, modified, or custom-made.
4. What impact would assistive technology have on caretakers?
5. Where do you think assistive technology and assistive robots fit into the future of our society?
6. Is there anyone else you think we should contact or interview to give us further insight on these topics?

Specific Questions for Education Professionals (optional questions for other interviewees based on experience):

1. What impact, positive or negative, do you see assistive robots having in the classroom?
2. What types of assistive robots would you use in your classroom?
3. How would you expect to use the robots in your class?

4. How can you see assistive technology aiding children's education financially?
5. How do you see this impacting specifically the special education classroom and students?

Survey Questions for Professionals who work with the aging population (optional questions for other interviewees based on experience):

1. How can you see assistive technology aiding the aging population financially?
2. What needs of the aging population can be aided by the use of assistive technology? How can assistive technology fill these gaps?

A.1.2 Interview Questions for Chapter 2

1. What interaction do you have currently with assistive technology?
2. What is your ideal method of interaction with an assistive robot?
3. What daily tasks would you appreciate help with from an assistive robot?
4. How often would you converse with a socially assistive robot?
5. What is your opinion on integrating assistive robots into a healthcare setting?
6. What level of control would you prefer an assistive robot to have over you?
7. What benefits do you feel that an assistive robot would have in your life?
8. What would be your main concerns on how an assistive robot would affect your life?
9. What potential barriers do you foresee in integrating robots into a healthcare setting?
10. What kind of aid would be required for you to effectively utilize an assistive robot?

A.1.3 Interview Questions for Chapter 3

For Users:

1. What physical features would you want your assistive robot to have? How human would you want them to look?
2. How human-like would you like an assistive robot to respond to you? Why?
3. How would you feel about using an assistive robotic device that does not ever turn all the way off?
4. How comfortable are you with the idea that the robot would share your data with family members or doctors?
5. What type of tasks would you want your assistive robot to be able to complete?
6. How would you like to interact with a robot? (ex: tablet, voice etc)
7. How would you feel about using a robot that made decisions based on observation, and not only on given directives?

For caregivers:

1. Would you feel apprehensive working with an assistive robot in your caregiving role? Why or why not?
2. What activities would you like an assistive robot to aid in?
3. What would be your ideal mode of interacting with an assistive robot (i.e. voice control, tablet, etc.)?
4. How would you like to interact with the assistive robot to help your caregiving capabilities?

A.1.4 Interview Questions for Chapter 4

For people over the age of 65:

1. When you think of challenges with living independently as you age, what daily functions come to mind?
2. What activities or functions would you be comfortable with an assistive robot performing?
3. If you have any formal or informal caregivers, would you be comfortable replacing them partially or fully with assistive robot technology?
4. What are your thoughts on having an assistive robot in your home?
5. Would you be more willing to allow an assistive robot in your home if it meant that you didn't have to move to an assisted living facility until later?

For educational professionals:

1. What tasks are most time-consuming in the classroom?
2. What teaching methods are most effective (visual, auditory, examples, hands-on)?
3. What activities would you be comfortable with a robot performing in a classroom? Are there any activities you would not be comfortable with a robot performing?
4. How much funding do you think would be available for an educational assistive robot? Where from? What obstacles might there be for funding?
5. What issues do you foresee in incorporating teaching robots into the classroom?

For rehabilitation:

1. Do you think an assistive robot would be able to give support to you or help you in your daily functions?
2. What type of work would you feel comfortable giving to assistive robots?

3. What components of a caregiver do you value the most? In other words, what components of a caregiver would you like to see implemented in an assistive robot?
4. What are your thoughts on artificial intelligence robots?
5. How much would you rely on a robot for everyday tasks?

A.1.5 Interview Questions for Chapter 5

For people with disabilities:

1. How will an assistive robot alleviate the challenges of living independently long term?
2. How costly do you think an assistive robot will be compared to a caretaker long term?
3. How will an assistive robot help with education or employment of people with disabilities and older adults long term?
4. How do you think assistive robotics will impact your mental and physical health long term?

For educational professionals:

1. What tasks would an assistive robot aid you in the classroom long term?
2. How do you think assistive robotics will impact your mental and physical health long term?
3. How do you think assistive robotics will help children and young adults achieve their long term educational goals?

4. How do you think assistive robotics will improve educational outcomes for children?

For rehabilitation professionals:

1. How do you think an assistive robot would be able to support you long term?
2. How do you think assistive robotics will impact your mental and physical health long term?