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Assistive technology for adults on the autism spectrum: A systematic survey

Manhua Wang, Ph.D.,
Virginia Tech, Blacksburg, Virginia, United States

Myounghoon Jeon, PhD
Virginia Tech, Blacksburg, Virginia, United States

Abstract

While the needs and care for children on the autism spectrum have been widely investigated, the intervention and services available to autistic adults have been overlooked for a long time. This survey paper reviewed 32 articles that described and evaluated assistive technologies that have been developed and evaluated through a complete circle of interactive product design from ideation, prototype, and user evaluation. These assistive technologies aim to improve independence and living quality in autistic adults. We extracted information from the perspective of requirement gathering, technology designing, and effectiveness of evaluation in the design cycle. We found a general lack of requirements-driven design, and the evaluation process was not standardized either. The lack of requirement gathering results in designs purely based on existing literature without targeting actual user needs. Our synthesis of included paper contributes to developing iterative design considerations in assistive technologies for autistic adults. We also suggest that assistive technologies for autistic adults shift some attention from assisting only autistic adults who require at least substantial support to embracing also those who have been living independently but rather have difficulties in social interaction. Assistive technologies for them have the potentials to help them consolidate and enhance their experiences in independent living.

Keywords

autistic adults; assistive technology; autism spectrum disorder; user-centered design

1 INTRODUCTION

Autism is prevalent among 1 in 44 children in the United States (Maenner et al., 2021a). Individuals on the autism spectrum are characterized by underdeveloped skills in social communication and interaction across multiple contexts, plus restricted and repetitive behaviors (American Psychiatric Association, 2013). According to the 2017 National Autism Indicators Report, approximately 50,000 individuals on the autism spectrum turn 18 years old each year in the United States (Roux et al., 2017), when they are expected to

manhua@vt.edu .

live independently. While great efforts have been exerted to identify autism and intervene at early ages, there is a shortage of research on supporting services and opportunities for autistic adults to live fulfilling lives and have meaningful outcomes. One of the objectives of the 2017 Interagency Autism Coordinating Committee (IACC, https://iacc.hhs.gov) in the United States is to support research that facilitates the acceptance, accommodation, inclusion, independence, and integration of autistic people into society.

1.1 A note regarding terminology

The authors acknowledge that the linguistic framing of autism has impacts on the autism community. Although the appropriate terminology used to describe individuals with a diagnosis of autism spectrum disorder (ASD) has been widely discussed in recent years, a clear consensus has not been reached in the literature regarding the most proper language (identity-first vs. person-first) for autistic people (Botha et al., 2021; Vivanti, 2020). While identity-first language (e.g., “autistic,” “autistic person”) received higher preference, “person on the autism spectrum” was rated with both higher preference and lowest offensiveness by the autism community (Bury et al., 2020). Thus, this paper uses both identity-first and person-first languages interchangeably and follows the suggestions on avoiding ableist language (Bottema-Beutel et al., 2021) to acknowledge the variation of term preferences and avoid indicating a stance that is beyond the scope of the present work.

1.2 Problem Statement

For a long time, a majority of assistive technologies and intervention programs for autistic people have focused on supporting young children, school-aged children, or adolescents (Tomczak, 2021), helping them enhance social skills in classroom settings or daily routines (Alabbas & Miller, 2019; Caldwell, 2020; Fage et al., 2018; Javed et al., 2020; Roldán-Álvarez et al., 2016). Different types of assistive technologies have been developed to provide early intervention to autistic children. Social stories, video modeling, and picture exchange communication systems are effective interventions for autistic individuals, especially children (Ali & Saad, 2016; Athbah, 2021; Camilleri et al., 2022; Flippin et al., 2010; McCoy & Hermansen, 2007). In addition, personal digital assistants (PDAs), such as tablets and smartphones (e.g., Weisblatt et al., 2019), can help with reducing autistic students’ reliance on other caregivers (Athbah, 2021). Social assistive robotics were found to be promising in enhancing communication skills (Syriopoulou-Delli & Gkiolnta, 2020) and preferred by autistic children (Barnes, Park, Howards, & Jeon, 2020). Emerging technologies, such as augmented reality (AR), have also shown positive effects on improving social communications skills in the autistic population (Khowaja et al., 2019). However, there is a lack of high-quality research studies that aim at young adults to help them with a successful transition to adulthood, or target adults in mid-to-late adulthood to support their independence (Howlin et al., 2015; Howlin & Taylor, 2015). A limited number of intervention studies for autistic adults were identified, and many of them suffer from limited quality (Taylor et al., 2012). In addition, services available to autistic adults are usually generic to individuals with intellectual disabilities (Howlin et al., 2015), which overlook the autism-focused requirements and, thus, lead to potentially insufficient intervention. The clinical guidelines of the United Kingdom’s National Institute for Health and Care Excellence were not able to provide recommendations on the specific type of treatment regarding adult intervention either (National Institute for Health and Care Excellence, 2013). Despite the limited number and quality of interventions, such programs and care are also at high costs (Howlin et al., 2015; Rogge & Janssen, 2019). Assistive technologies, as an alternative to traditional intervention that requires the involvement of interventionists and other key personnel, can be used independently or combined with intervention visits as self-pacing intervention, which can potentially reduce the cost of care and consolidate the intervention sessions (Athbah, 2021; Yee, 2012).

The negligence of autistic adults in general results in the limited literature in summarizing assistive technologies available to them. Previous reviews have synthesized wearable assistive technologies for autism, focusing on social interactions (Benssassi et al., 2018), physiological and emotional monitoring (Taj-Eldin et al., 2018), or on a broader spectrum of functional support (Williams & Gilbert, 2020). Reviews from Benssassi et al. (2018) and Taj-Eldin et al. (2018) approached the analysis from the aspect of technology, investigating the capabilities and limitations of the equipped sensors and supported functionalities. Williams and Gilbert (2020) conducted their analysis by concentrating on the targeted needs addressed by those technologies. Augmentative and alternative communication (ACC) technologies as an intervention to teach social-communication skills are also reviewed in previous research (Holyfield et al., 2017; Morin et al., 2018). Although these studies include broad coverage of the autistic population in terms of age, the needs and concerns of autistic adults can be essentially different from children. As autistic individuals age, they usually show improvement in the severity of symptoms of autism or even no obvious signs of autism in adulthood (Anderson et al., 2014). Independent living or employment in adulthood becomes more of a focus and requires some type of intervention. In addition to integrating the age groups, existing reviews have not discussed how to effectively design and evaluate technologies for autistic adults in terms of intervention effect and social acceptance. Reviews on ACC technologies analyzed the quality and findings from the evaluation research on the effectiveness of using ACC technologies (Holyfield et al., 2017; Morin et al., 2018). However, the lifecycle of assistive technology design, which iterates from the idea generation, design, evaluation, and revision, has been overlooked in previous review articles. In this way, not only is there limited literature about autistic adults, but also inadequate knowledge to understand the mental, physical or social needs of this population and address their needs with well-designed and evaluated assistive technologies.

The present survey paper aims to examine the complete lifecycle of technology designed for autistic adults. Particularly, this study is interested in how assistive technologies are proposed and evaluated to address the needs of autistic adults. The specific research questions to be answered include:

RQ1: What requirement gathering methodologies and design principles are used to guide assistive technology design?

RQ2: What are the characteristics of already proposed assistive technologies?

RQ2.1 What were the device forms of the technologies?

RQ2.2 What were the challenges that the proposed technologies attempted to address?

RQ3: What are the evaluating processes to assess the effectiveness of the proposed assistive technologies?

RQ3.1 What research methods were used?

RQ3.2 What were the characteristics of included participants?

RQ3.3 What dependent measures were considered?

By answering these questions, the current paper is able to identify the underrepresented research topics on assistive technologies for adults on the autism spectrum, while also generating a new classification scheme to characterize future assistive technologies in a more systematic way, which makes the comparison among technologies possible. In addition, with the findings, this survey paper also summarizes design guidelines and considerations, along with the evaluation methods to develop and assess assistive technologies for autistic adults. These guidelines can be beneficial to future research studies or design teams to deliver better solutions for this target population.

2 METHOD

This survey paper followed the 3-step review process in a systematic review recommended by Kitchenham and Charters (2007): planning, conducting, and reporting. The process was refined slightly to suit the current research aims. The need identification and research question(s) specification in the planning phase for the current study have been posed in the previous section. This section describes the remaining components of the review protocol–search strategy, study selection criteria, study selection procedures, and data extraction strategy.

2.1 Database Sources and Search Strategy

Five databases were searched, including Web of Science, ACM Digital Library, EBSCOHost, Scopus, and IEEE Xplore Digital Library. The articles searched were published before or on August 3rd, 2021. Two groups of keywords (KW) were used to explore these databases. KW1 was related to autism. We applied the truncation technique (e.g., “autis*”) to broaden our search. KW2 was related to assistive technology. The proximity searching strategy was used to connect two components of “assistive technology” to ensure a comprehensive pool of citations. In the present paper, we use “Near Operator” to find these two components if they are a maximum of five words apart from one another, regardless of the order of appearance. The synonyms of “assistive” (i.e., “adaptive”, “helping”, “supportive”) and “technology” (i.e., “device”, “tool”) were also included to facilitate the comprehensiveness, to whom we also applied truncation technique. Table 1 lists the search syntaxes tailored for each database, and the number of results returned. We did not include search terms that constrained the target group as adults to avoid losing related articles early.

2.2 Article Selection

An original research study was included if it proposed or developed and evaluated an assistive technology to support adult individuals on the autism spectrum. Defined by the

US Assistive Technology Act of 2004, an assistive technology device is "any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities". In this study, we considered any technologies, including training techniques, that help adults on the autism spectrum perform tasks and activities necessary for their daily lives. We acknowledge that some articles documented sophisticated processes of developing assistive technologies (e.g., Rapp et al., 2018). However, as we were specifically interested in analyzing a complete development cycle of assistive technologies, articles solely in the concept development stage were excluded.

For the purpose of this review paper, individuals aged 20 or higher are considered adults, with the young-adult group aged between 20 and 39, the middle-aged-adult group aged between 40 and 59, and the older-adult group aged above 60 (Heckhausen et al., 1989).

2.2.1 Screening Process.—

Two levels of screening were conducted to select eligible articles. The authors screened each article's title and abstract in Covidence (www.covidence.org) before moving to full-text screening.

Based on the objective of this review and with the definitions and constraints clarified above, we developed the following exclusion criteria for the first-level title and abstract screening:

1. The target population was not or did not include individuals on the autism spectrum.
2. The article did not introduce any assistive technology, but other behavioral intervention programs.
3. The article was not written in English.
4. The article was not a research article, but was instead a review, editorial note, or opinion paper.

After the title-and-abstract screening, three additional exclusion criteria were added to the full-text screening stage to narrow down the citations further to be analyzed:

1. No user studies were carried out to evaluate the effectiveness of the introduced assistive technology, or the user evaluation process was described briefly without participants' information or experimental design.
2. The target users were non-adults, or the technology was aimed at autistic adults but only used non-adult participants to evaluate. Note that articles excluded for this reason still documented their user evaluation process on the proposed technology. In this way, we were able to distinguish them from articles excluded solely because of the lack of user evaluation processes.

Figure 1 displays the logic and flow of the screening process. Among the citations excluded in the full-text screening stage, a total of 126 studies were not designed to support adults but focused on children mostly and adolescents occasionally. We did not identify robot-related technologies. However, we believe that robotic technologies are essentially different from other non-social technologies reviewed in the present study. First, the design considerations of embodied agents are largely different from other types of devices that do not have embodiment. No matter the types of robots used—humanoid or non-humanoid, robots have a variety of stimulus elements, including but not limited to appearance, biological motion, clothes, hairstyle, voice volume, and facial expressions (Kumazaki et al., 2020). Some factors (e.g., appearance and cloth) are preset by the manufacturer and, thus, are not available to be manipulated and optimized. Other elements, such as voice and gaze, retain a high social presence. This characteristic essentially differentiates robots from other assistive technologies, such as personal devices that are more portable and accessible. Second, robots have shown great potential to assist children on the autism spectrum, and there have been extensive reviews on the usage of robots in therapy or interventions for autism (e.g., Alabdulkareem et al., 2022; Kumazaki et al., 2020; Saleh et al., 2020). Due to these reasons, we also suggest a separate review of robotic technologies for autistic adults in the future when there is sufficient evidence. We finally included 32 studies focusing on assistive technologies for adults, which account for only 19% of studies among all 165 studies (32 studies included plus 133 studies excluded that were not for adults) that included both technology description and evaluation.

2.2.2 Data Extraction and Analysis—

A data extraction spreadsheet was developed, consisting of the classification scheme, which can be categorized into two general aspects.

1. The proposed assistive technologies themselves. This includes the form of the technology, the purpose or supporting area of the technologies, and the requirement gathering methodologies and design principles adopted in the development process.

2. The evaluation methods and perspectives used to assess the effectiveness of the technology. The scheme included in the framework was determined to capture the complete development process from the requirement gathering, design, and evaluation.

2.2.3 Classification Scheme for Assistive Technology.—

Nine analysis aspects were taken into consideration to categorize the proposed assistive technologies. These aspects mainly cover the requirement gathering and design process that contributes to the delivery of a prototype or a launched product.

Technology Description is a brief summary of the technology proposed in the literature, including the technology name and format.

Novelty indicates whether the evaluated assistive technology is (1) an existing technology or device, (2) a novel implementation or usage of an existing application on the existing technology or device, (3) a newly designed application or add-on on the existing technology or device, or (4) a completely new proposed system.

Degree of Advanced Technologies refers to the degree of advanced technologies adopted. It can be related to a continuum of low-tech to high-tech devices (Bryant et al., 2010), from the least advanced category (e.g., task cards), more advanced category (e.g., computer-based video instruction), to the most advanced category (e.g., natural language processing-based text-to-speech software).

Requirement Gathering Methodologies refer to the methods (e.g., interviews, focus groups) used to gather the user needs and narrow down the problem to be solved.

Design Principles refer to any principles (e.g., universal design guidelines), either existing or developed during the requirement gathering process, used to guide the prototype development.

Device Form depicts either the carrier of the technology in an application or website form or the type of the device itself. This category includes but is not limited to personal digital assistants (e.g., iPod), virtual environments, or computer-based systems.

Use Context refers to when or where the technology can be used. This category includes but is not limited to using in day-to-day activities, using in the training session, using in therapy programs, using at home, and using in the workplace.

Modality refers to the perception channel required for using assistive technology. This includes visual, auditory, tactile, olfactory, and gustatory.

Targeted Need(s) is the most critical category in the analysis of technologies aspect. Previous research has different taxonomies about how assistive technologies could support individuals on the autism spectrum. Most technologies target adaptive functioning in contrast to intellectual functioning. The social interaction and communication skills to be supported were subdivided into emotion recognition, eye contact and joint attention, proximity and distance, atypical prosody, stereotypical behaviors, and general social skills (Benssassi et al., 2018). A recently published survey paper identified the following intervention categories: (1) augmenting existing behavior interventions, (2) emotional intelligence drills, (3) social skills training, (4) vocational and community rehabilitation, (5) sensorimotor support, (6) emotional support and self-regulation, (7) communication support, and (8) executive function support (Williams & Gilbert, 2020). A lay version of the support areas can be home living, community living, lifelong learning, employment, health and safety, social, and protection, and advocacy (Bryant et al., 2010; Thompson et al., 2004). Based on the previous categorization and the inductive analysis of the included literature in this study, a modified category is established to incorporate the following targeted needs:

Communication and social skills refer to the ability to perform social norms and express opinions in proper ways (e.g., prosody, loudness).

Vocational rehabilitation focuses on supporting individuals to access, maintain, or return to employment or other occupation.

Community living skills include individuals' ability to be independent of community living skills such as shopping, traveling, wayfinding, and driving.

Home living skills include individuals' independence in performing day-to-day living skills, like cooking and cleaning.

Emotional intelligence includes emotion monitoring, recognition, expression, and regulation.

Self-promotion refers to individuals' ability to conduct lifelong learning, which requires reading, comprehension, and self-management abilities.

Behavior interventions *directly* help individuals overcome repetitive and stereotyped behaviors that interfere with users' current tasks or potentially harm themselves. The primary objective of assistive technologies categorized into behavior interventions is to reduce repetitive and stereotyped behaviors. This might result in other side benefits such as enhanced living skills. However, such extended benefits do not qualify them into other categories in the present study.

Health and safety include both mental and physical health care.

It is noticed that these target needs might have subsequent benefits if the beneficial effects are well maintained and generalized. However, we categorized the assistive technologies based on their primary objectives when being designed, instead of taking all collateral benefits into account.

2.2.4 Classification Scheme for Evaluation Process.—The methods used to evaluate the proposed technology were analyzed from the following aspects.

Number and Types of Participants refer to the characteristics of participants recruited from the evaluation process and whether they are diagnosed with ASD. Their ages and levels of cognitive functioning were included if listed in the paper.

Evaluation Methodologies refer to the experimental design or data-gathering methods adopted in the assessment process, such as interviews, between-groups experiment designs, and single-case experiment designs.

Stages Evaluated are considered since the ultimate goal of this technology is to help people on the autism spectrum regain independence. Therefore, a better evaluation should also consider the maintenance and generalization in addition to the effects right after intervention. In addition to the intervention effectiveness, user adaptation–how participants react to the technology and their experiences–is also crucial because it affects the actual usage of technologies.

Dependent Measures include the indicators of technology adaptation, effectiveness, generalization, or maintenance. The measures can be quantitative (e.g., percentage task completion) or qualitative (e.g., participants' verbal or written comments, subjective (e.g., questionnaire data), or physiological (e.g., heart rate, salivary cortisol levels).

Major Findings section summarizes the key findings from the evaluation session.

3 RESULTS

3.1 Geographical Distribution and Chronological Trends

A total of 32 publications met the inclusion criteria and were reviewed for qualitative data analysis. Table 2 summarizes the location distribution of the included citations. Researchers from the United States contributed 17 (53%) studies. Four (13%) studies were collaborated by multinational researchers. Researchers from the United Kingdom and Spain each contributed three studies (9%) to the included citations, while researchers from other European countries (France, Italy, Portugal, and Germany) and Japan each contributed one study to the included citation pool.

Since the first study in 2004 that aimed to use an adapted bar code reader to teach item classifying skills to an adult with autism (Herrera & Labajo, 2004), there has been an increasing number of studies dedicated to designing and evaluating assistive technologies targeting autistic adults (Figure 2). We also identified a trend of increased technology advancement adopted into assistive technologies, from least advanced technologies, such as video modeling with portable devices (Burckley et al., 2015; Campillo et al., 2014), to more advanced technologies, such as well-developed applications (in contrast to video importing and exporting applications) for personal digital assistants (PDAs) (Burke et al., 2013; McGowan et al., 2017) or devices with multiple sensors (Tang et al., 2016), to most advanced technologies such as virtual reality (Bernardes et al., 2015; Bozgeyikli et al., 2018; McCleery et al., 2020; Saiano et al., 2015) and augmented reality (Boyd et al., 2016; Grund et al., 2020; Lin et al., 2020) environments, natural language processing (Abdallah et al., 2019; Cassidy et al., 2016), or facial/speech recognition techniques (Boyd et al., 2016; Cassidy et al., 2016). Such an improvement in technological advancement is foreseeable as the advanced technologies become publicly available and affordable.

3.2 Assistive Technology for Autistic Adults

Following the data-extraction schemes defined in the previous section, we extracted information from the full-text articles and categorized them into a higher classification level for each scheme.

3.2.1 Requirement Gathering Methodologies and Design Principles.

—Among all included articles, 18 studies proposed new assistive technologies, while the remaining 14 studies either adapted the existing technologies–mostly existing applications–as assistive technologies for autistic adults, or solely evaluated the effectiveness of the existing assistive technologies for autistic adults.

None of the studies that examined existing studies included any requirement gathering methodology, but one of them (Burke et al., 2013) specified the design principles used. Table 3 presents the requirement gathering methodologies and design principles adopted for studies that proposed new systems. Semi-structured and structured interviews were mostly used to gather requirements and user needs. Except for one study (Evmenova et al., 2019) that interviewed target users themselves, the other seven studies all conducted interviews with caregivers (e.g., therapists, family members, social workers) or subject matter experts (e.g., psychologists, doctors, job coaches). This pattern was not surprising as users on the autism spectrum usually face difficulties in expressing their needs or desires, or simply have undeveloped verbal communication abilities, or are not available to be involved (Hervás et al., 2019). Observation is an alternative to gathering user needs directly from users as it does not require active communication with them. Two studies observed autistic adults from different settings. Hong et al. (2012) observed adults with high-functioning autism at weekly social group meetings to gain design inspiration. Tang et al. (2016) observed individuals on the autism spectrum in various settings (e.g., library, food catering service, home) to understand user needs and challenges for their product design and development.

In addition, two studies specified their multidisciplinary design team (Boyd et al., 2016; Pérez-Fuster et al., 2019), both including computer engineers or electronic engineers who helped with system construction, experts such as psychologists and speech & language pathologists who understand and work with the target autistic population or have expertise in the targeted needs to be addressed. Boyd et al. (2016)(2016) also included a graphic designer to help them design the interface of the proposed technology.

3.2.2 Device Form.—Table 4 lists the device forms of assistive technologies classified into four categories: (1) personal digital assistants (PDAs), (2) virtual environments, (3) computer-based systems, and (4) physical objects. Nineteen (59%) studies used PDAs as carriers of the proposed or evaluated technologies. These PDAs covered both iOS and Android platforms and varied from popular Apple products, such as iPad, iPod, and iPhone, to devices specifically designed for augmentative communication, such as DynaVox Vmax Device (Hyppa-Martin et al., 2020; Maenner et al., 2021b). Eight (25%) studies adopted augmented reality (AR) or virtual reality (VR) techniques in the proposed assistive technology or evaluated the application of the existing AR/VR environment. Seven (22%) studies embedded their technology in computer-based systems, the form of which included web applications (Pérez-Fuster et al., 2019), laptop applications (Cassidy et al., 2016; McGowan et al., 2017, 2021; Tsangouri et al., 2016), and electronic platform (Cerga-Pashoja et al., 2019). We also identified three studies that provided assistive technologies attached to the existing object/platform in users' real-life settings or workplaces. Herrera and Labajo (2004) modified the barcode scanner with coloring stickers to help an adult with autism with her item classification skills in a store. Pérez-Fuster et al. (2019) combined a mobile application with an LED lighting system to improve the independence of autistic adults. Grund et al. (2020) applied AR techniques to the workstation in an electronic production environment, aiming to improve the task performance and user experience of employers on the autism spectrum on electronic assembling tasks. Sumioka et al. (2021) tested Hugvie, a human-like pillow communication device, on its ability to decrease the stress perceived by autistic adults when talking to strangers on the phone.

The results indicate that PDAs are popular carriers of assistive technologies as they are portable and more accessible than VR/AR devices or computer-based systems. Some assistive technologies were available through multiple device forms to users on the autism spectrum. For instance, a visual software application named Tic-Tac evaluated by Campillo et al. (2014), was available on smartphones, tablets, as well as personal computers and had various versions in Polish, English, French, and Spanish. Multiple device forms were also designed for users on the autism spectrum and their caregivers. For instance, Pérez-Fuster et al. (2019) developed the ETIC system with multiple device forms aiming to improve participants' home living skills. The system consisted of a web interface designed for parents, educators, and practitioners to manage care receivers' profiles, a mobile application, and a LED lighting system at home for adults with autism to assist them in performing tasks at home. The immersive mobile VR tool system developed by McCleery et al. (2020) also included an iPad version for the therapist to control and monitor virtual scenes for their clients, while the immersive VR experiences for their care receives were provided through a smartphone.

3.2.3 Modality.—The proposed or evaluated technology in 30 out of 32 studies (94%) provided visual information and feedback to the users, 17 of which also incorporated auditory information in addition to visual feedback. For the remaining two studies that did not integrate visual feedback, the vocal communication tool developed by Abdallah et al. (2019) only generated auditory commands when there was a request from the autistic user, while the Hugvie only provided tactile feedback for users with autism on the phone (Sumioka et al., 2021). Three studies also utilized tactile feedback in addition to visual and auditory information. Bozgeyikli et al. (2018) used tactile feedback when users made actual contact with the target object (i.e., boxes to be shelved) in the VR environment. Tang et al. (2016) used tactile feedback through the mobile app as prompts for the next steps in an activity. The haptic feedback in the empathic system developed by Lin et al. (2020) was used to indicate the status change of the emotion reading.

3.2.4 Use Context and Targeted Challenges.—Table 5 synthesized the number of articles for each targeted need and the use context of the proposed assistive technology. Some assistive technologies mentioned in the included articles were designed to solve multiple challenges (Campillo et al., 2014; Hong et al., 2012; Lin et al., 2020; McGowan et al., 2017, 2021), while most of them targeted a single challenge.

Vocational rehabilitation was the challenge most frequently addressed for autistic adults; nine studies examined assistive technologies aimed to help autistic adults to prepare for interviews (Hong et al., 2012), match their skills with tasks (Walsh et al., 2020), or improve their skills in the workplace (Bozgeyikli et al., 2018; Burke et al., 2010, 2013; Gentry et al., 2012; Grund et al., 2020; Hayes et al., 2015; Herrera & Labajo, 2004). Most of the technologies proposed for vocational rehabilitation were suitable to use in training sessions or in the workplace directly. Some of them can also be used at home for skill consolidation.

Communication and social skills were the second most addressed challenges. These studies attempted to improve communication skills in autistic adults with different levels of vocal abilities. Five of these eight studies aimed to help autistic adults who had underdeveloped verbal communication skills (Hyppa-Martin et al., 2020; McGowan et al., 2017, 2021; Nepo et al., 2017; Wendt et al., 2019). Two studies focused on facilitating users' self-awareness when interacting with others, such as emotional awareness (Lin et al., 2020), prosody and loudness (Boyd et al., 2016). McCleery et al. (2020) also attempted to improve police interaction skills in adolescents and autistic adults. These technologies designed to improve communication skills were primarily used in day-to-day communication and training or therapy sessions to help users regain or develop alternative communication skills.

Community living skills were also addressed frequently. These technologies aimed to improve travel or navigation-related skills, such as taking public transportation (Bernardes et al., 2015), street crossing skills (Saiano et al., 2015), communicating locations (Horn et al., 2021), and shopping (Burckley et al., 2015). Other studies aimed to facilitate step-by-step activities in the community (Wright, 2016) or provide social networks for autistic adults to ask skill-related questions (Hong et al., 2012). Technologies described in these studies were used in the use context of community activities or training sessions.

Emotional intelligence, home living skills, and self-promotion were three challenges addressed equally frequently. Emotion regulation and emotion recognition were two aspects targeted in four studies that addressed the challenge related to emotional intelligence. Campillo et al. (2014) and Sumioka et al. (2021) aimed to regulate stress experienced by autistic adults during waiting or on calls with strangers in day-to-day activities, while Tsangouri et al. (2016) and Cassidy et al. (2016) focused on teaching individuals on the autism spectrum to recognize or express emotions in training sessions or for practicing at home. Technologies aiming to improve home living skills focus on cleaning tasks (Pérez-Fuster et al., 2019), cooking and eating (Tang et al., 2016), communication with family members (Abdallah et al., 2019), and leisure activity (Maenner et al., 2021b). As expected, these technologies for home living skills were designed to use at home. Previous studies also attempted to promote long-time learning through self-management skills at school (Evmenova et al., 2019), improve self-esteem through therapy sessions (McGowan et al., 2017, 2021), or reading comprehension (Cerga-Pashoja et al., 2019).

Only one study provided a technology intervention in anxiety-related repetitive behaviors (Campillo et al., 2014). None of the studies included addressed challenges with health and safety in autistic adults.

3.3 User Evaluation of Proposed Technology

3.3.1 Evaluation Methodology.—The evaluation methods used to assess the effectiveness of assistive technologies can be classified into three main categories: (1) user studies, (2) experimental studies, and (3) interviews. User studies were divided into pure observational studies and usability testing. The experimental study designs can be further classified into between-group experimental designs and single-case experimental designs (SCEDs). Between groups experimental designs were further categorized into neurotypical vs. autism groups or treatment vs. control groups. SCEDs, also referred to as within-subject designs (Ma, 2011), were primarily used to examine the effectiveness of interventions (Krasny-Pacini & Evans, 2018; Smith, 2012). We identified five types of SCEDs used in the included studies. A detailed description of each type of SCED can be found in the review paper by Byiers et al. (2012). Table 6 outlines the evaluation methods adopted in the included studies.

Six studies (19%) conducted user studies to evaluate assistive technologies. Two studies simply observed the way participants interacted with the technologies. None of them specified any coding techniques they used to transcribe and debrief the observation sessions. Four studies conducted usability testing, where participants were asked to interact with or complete tasks using the technologies, followed by filling out subjective rating scales.

Twenty-six (81%) studies conducted experimental studies of various kinds, among which the SCEDs were the most popular research designs (18 studies), with the multiple-probe design as the most used type (eight studies). Six studies adopted between groups experimental designs, which compared the effectiveness of the technology intervention between autistic adults and their counterparts, or between treatment groups and control groups.

Finally, four studies (13%) conducted interviews to understand the impact of their proposed technologies. The formats of interviews varied from in-depth individual interviews (Boyd et al., 2016; McGowan et al., 2021), to group interviews (Hong et al., 2012).

Only one study (Boyd et al., 2016) adopted multiple evaluation methods to validate their proposed technology in both lab-controlled experiments and naturalistic settings.

3.3.2 Evaluated Intervention Stages.—Figure 4 displays the trends of the intervention stages evaluated in the included studies. Twenty-seven (84%) studies evaluated the effectiveness of the technology. The remaining five studies did not evaluate the effectiveness but evaluated the adaptation stage instead, where researchers gained information about participants' feedback towards the technology on their perception, satisfaction, acceptance (Bernardes et al., 2015; Cassidy et al., 2016), likability (Evmenova et al., 2019), technology comprehension (Bernardes et al., 2015), or safety of use, without any intervention session. Some studies also evaluated skill generalization (Maenner et al., 2021b; Nepo et al., 2017; Saiano et al., 2015) or skill maintenance (Gentry et al., 2015; Hyppa-Martin et al., 2020) after confirming the effectiveness. Only four studies examined all three stages, from instant effectiveness, generalization, to maintenance (Burckley et al., 2015; Burke et al., 2010; Horn et al., 2021; Wendt et al., 2019). The evaluation of skill maintenance was administrated after as short as two weeks (Hyppa-Martin et al., 2020) to as long as 24 weeks after the first treatment (Gentry et al., 2015). We also found that skill generalization and maintenance were not evaluated independently but usually came after evaluating technology effectiveness.

3.3.3 Participants.—Table 7 synthesizes the participants' IQ score range, age range, and sex for each targeted need addressed. The participants included in this table were limited to autistic adults. Less than half of the studies (N = 11) reported the composite or full-scale IQ score or score range of their participants with autism. However, the instruments used to measure the IQ score varied among studies, making it difficult to compare the level of intelligence across studies and across targeted needs addressed. We observed that technologies that assisted community living skills and home living skills targeted autistic adults who had a below-average IQ score range in general. As for the age range, researchers chose a variety of participants that covers from young adults to people in their mid-to-late adulthood. In terms of sex ratio, 110 females and 347 males in total were included as participants, with a male-to-female ratio of 3.2: 1. This ratio is consistent with the higher rate of autism diagnosis in males than females. It also supports the finding of a true male-to-female ratio closer to 3:1 without diagnostic sex bias (Loomes et al., 2017).

Three studies that compared the technology usage between autism groups and neurotypical groups (Bernardes et al., 2015; Bozgeyikli et al., 2018; Cassidy et al., 2016) also provided the age and sex information of their neurotypical groups (Table 8). While the age range between groups was well-controlled, the sex difference seemed hard to control.

3.3.4 Dependent Measures.—The dependent measures assessed in the included studies were categorized into four main categories: (1) quantified performance, (2) subjective questionnaires for participants, (3) subjective questionnaires for caregivers, and (4) social validity (Table 9).

Twenty-seven (84%) studies that evaluated the effectiveness of the technology all collected some forms of quantified performance, except for one that collected physiological data–salivary cortisol levels as an indicator of anxiety level (Sumioka et al., 2021). The most widely used performance indicator was the percentage of steps correctly completed for a task (Bernardes et al., 2015; Burckley et al., 2015; Burke et al., 2010, 2013; Horn et al., 2021; Wright, 2016). Questionnaires for participants were used to collect their perceptions of the task difficulty or the assistive technology design. User satisfaction was frequently assessed, especially for studies that looked at technology adaptation. Questionnaires for caregivers were used in studies as an indirect measure of skill generalization or maintenance. Finally, studies assessing social validity either used established measures or a self-developed survey for social validity assessment.

4 DISCUSSION

The purpose of this survey is to understand the process of developing and evaluating an assistive technology for autistic adults. The interpretation and discussion of the data delineated in the following sections will return to the research questions posed in the introduction section. This survey also contributed to the development of several design guidelines and considerations, followed by future work discussed at the end.

4.1 RQ1: What requirement gathering methodologies and design principles are used to guide assistive technology design?

Findings from section 3.2.1 uncover the concern that not enough emphasis has been given to the requirement gathering process that is mandatory for the development of technologies. Researchers either evaluated the intervention from existing technologies or based their development on existing literature without engaging any potential users or stakeholders. These studies fell into the trap of the designer’s conceptual model that overlooked the actual needs of users or delivered products that might not solve the problems appropriately. Only nine papers carried out the requirement gathering process to learn user needs and challenges through interviews and observations. It is noticed that our survey only included research attempts that had a relatively complete product design from ideation, prototype, to user evaluation. The actual proportion of studies that included the requirement gathering process could be much smaller if all attempts were considered. This lack of needs analysis was also found in developing technologies for children with autism (Spiel, 2018), where 76.2% (n = 138) included studies designed and developed technologies based solely on existing literature, and only 9.4% (n = 17) studies adopted a participatory design (PD) approach where end-users also served as co-designers and are actively engaged in the design process.

While PD is a powerful tool in delivering technological solutions to autistic adults (den Houting et al., 2021; Fletcher-Watson et al., 2019), it should be used carefully when designing assistive technologies for individuals on the autism spectrum, some of whom are limited in their social and verbal communication skills in general. User-centered design (UCD) approach that also focuses on the user needs and tasks in an iterative process (Sharp et al., 2019) with less active user participation can be complementary to delivering solutions to the needs of autistic adults. One of three principles for the UCD is "early focus on users and tasks" (Gould & Lewis, 1985), instructing researchers and designers to learn who the users will be. Their characteristics and needs can be discovered by observing users performing routine tasks and their tasks' nature (Sharp et al., 2019). The challenges faced by users can also be learned and dug into through interviews. It is worth mentioning that different from the general product design process, which usually includes opinions directly from target users, the design process of an assistive technology targeting the autistic audience seems to additionally include opinions from target users' caregivers, such as their family members, training coaches, care workers, and therapists. All eight studies that conducted interviews as their requirement gathering methods interviewed either caregivers or experts, while only one study also interviewed target users with unknown characteristics (e.g., IQ score, verbal ability). Considering that these key stakeholders interact with autistic individuals frequently, their concerns and opinions are valuable and indispensable. In addition, some individuals on the autism spectrum with non-verbal skills might not be capable of conveying their own needs verbally and clearly, which further emphasizes the importance of having their caregivers involved in the design process. Note that we do not mean that stakeholders' opinions can override or replace autistic adults' opinions. But we are emphasizing that it is also important to hear stakeholders' perspectives.

4.2 RQ2: What are the characteristics of already proposed assistive technologies?

4.2.1 RQ2.1 What were the device forms of the technologies?—Personal digital assistants (PDAs) are widely used as carriers for the proposed technologies, mainly due to their portability, accessibility and affordability, familiarity, and ease of use for different ages and cognitive abilities (Pérez-Fuster et al., 2019). The findings also suggest that the choice of the device form also depends on and is limited by the target needs to be addressed. For example, PDAs are a great option for video modeling that simply shows videos or images; however, they may not be of great use when targeting mobility issues. Saiano et al. (2015) aimed to develop a technology to support street crossing skills, which can benefit from practices without potential dangers faced on the streets. Therefore, they utilized VR techniques, which were more appropriate and more effective than solely using video modeling.

We also identified a trend in adopting more advanced technologies over the years. As emerging technologies such as artificial intelligence (AI)-featured techniques are mature and more accessible to the general public, we anticipate that more advanced technologies adopted to help individuals on the autism spectrum can improve their independence and mobility.

4.2.2 RQ2.2 What were the challenges that the proposed technologies attempted to address?—

The top two frequently addressed challenges are Vocational Rehabilitation and Communication and Social Skills, which are consistent with the main characteristics of autism as underdeveloped social communication and social interaction skills (American Psychiatric Association, 2013). Technologies targeting children with autism were also found to mainly focus on communication and social skills (Spiel, 2018), further supporting the widely accepted fact about underdeveloped communication and social skills in individuals on the autism spectrum.

While communication and social skills remain a general challenge across ages, the purpose of assistive technologies for autistic adults has shifted to vocational rehabilitation compared to those for children. However, the current effort in vocational rehabilitation is not comprehensive. All nine studies focused on either preparing the participants for employment or helping them better finish their particular job. No studies attempted to facilitate collaboration among neurodiverse workers, where communication skills are also highly involved.

4.3 RQ3: What are the evaluating processes to assess the effectiveness of the proposed assistive technologies?

Another principle of UCD is "empirical measurement", which emphasizes measuring users' reactions and performance to the proposed system throughout the iterative process (Sharp et al., 2019). To evaluate a product, a plan or a research design must be outlined first, followed by the determination of the participants included and the dependent measures that guided the data collection process.

4.3.1 RQ3.1 What research methods were used?—

Single-case experiment designs (SCEDs) were frequently used in the included study to assess the effectiveness of the intervention provided by the proposed technologies. SCEDs, which have been used for over a half-decade, especially in education and psychology, is a set of experimental designs that aim to test the effect of an intervention using a small number of participants (Krasny-Pacini & Evans, 2018). Considering the scarcity of autistic participants, using SCEDs is an optimal option for lab-controlled studies.

Multiple-probe/multiple-baseline design was the most used experimental design, which examines the effect of a single intervention or an independent variable across three or more individuals (Burke et al., 2010, 2013; Horn et al., 2021; Maenner et al., 2021b; Nepo et al., 2017; Wendt et al., 2019), behaviors (Wright, 2016), stimuli (Hyppa-Martin et al., 2020), or settings (Burckley et al., 2015). Most studies applied interventions at different times for different individuals. Thus, some individuals remained in the baseline for some time before receiving the intervention. Because the replication of the experimental effect is across conditions in the multiple-probe/multiple-baseline design, this type of SCED does not require the withdrawal of the intervention (Byiers et al., 2012), which makes them more appropriate if researchers do not expect a return to baseline levels. However, a return to baseline levels can occur due to skill or memory degradation. In this case, reversal (ABAB) design is more appropriate to justify the effectiveness over repeated exposure or if the acquired skills cannot be well maintained.

Most studies included provided one solution or treatment to an addressed challenge. If alternative solutions or multiple candidate treatments are available, alternating treatment design is an option to evaluate multiple treatments.

A few studies also conducted user studies and interviews to evaluate their technologies, which we believe was neither compelling enough, when used independently, to advocate the effectiveness and acceptance of the proposed technology, nor did it assure the continuous usage of the technology. Another concern we have is the generalization and the maintenance of the skill acquired with assistive technology. Only nine studies examined the generalization or maintenance of the intervention. It was unclear whether users were required to utilize the assistive technology for some time and whether they were willing to do so. A distinction between one-time intervention and repeated assistance should be made to categorize assistive technologies better.

4.3.2 RQ3.2 What were the characteristics of included participants?—

Interestingly, the analysis of the included studies regarding the participants' age distribution for each targeted need revealed a wide range of ages covered from young adulthood to mid-to-late adulthood. This wide distribution promotes the generalization and acceptance of the proposed technologies.

Not many studies included information related to participants' IQ scores. Different assessment instruments were used for those who reported the scores, which makes it difficult for results generalization and comparison across different studies. Reporting IQ scores is critical to evaluating the effectiveness of participants' responses to questionnaires or materials related to reading comprehension. Participants with below-average verbal IQ may not be able to understand the questionnaire items, a fact that can become a critical exclusion criterion when determining the participants' eligibility during the process of study planning. However, considering that some participants' verbal IQ can be equivalent to children's verbal ability, pictorial scales such as the Smileyometer (Read, 2008), where the point Likert scale was represented by faces, could be an alternative approach to gathering opinions from autistic adults with underdeveloped verbal communication skills. The Smileyometer has been adopted in extensive research on developing technologies or training plains for autistic children (e.g., Benton et al., 2012; Mairena et al., 2019; Malinverni et al., 2017), and is worth trying to apply to product design for autistic adults.

On the other hand, we acknowledge that autistic adults may already be living independently, and such clinical assessments are not part of their self-knowledge. Thus, alternative ways to describe the levels of independence functioning can be more helpful. For example, the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5) provides a description of three-level of autism: (1) requires support, (2) requires substantial support, and (3) requires very substantial support (American Psychiatric Association, 2013). This information can suffice for the purpose of delineating the independence level and are less intrusive and ultimately more helpful and understandable for designers regarding user experience design.

4.3.3 RQ3.3 What dependent measures are considered?—
Almost all studies adopted quantitative measures of various types that suited their research questions and experimental tasks. Results from quantitative measures can provide substantial evidence to support the effectiveness of technology intervention.

Seven studies also included various types of social validity assessments. Social validity measurement is a measure to assess treatment acceptability. It is critical in evidence-based practice and can reveal significant and unanticipated intervention effects (Strain et al., 2012). When combined with the single-case experiment designs, results from social validity could further indicate the long-term effects of proposed technologies.

4.4 Design Considerations

With the findings from this survey paper, we summarize the design guidelines based on the general UCD approach and iterative design process. Figure 5 displays the design cycles with highlights on suggestions specific to autistic adults.

A successful product design always starts from the requirement gathering process. Before identifying user needs, we suggest identifying target users, especially considering that autism exhibits a broad spectrum, and the challenges faced by people on different spectrum can considerably vary. Narrowing down the target user is also helpful in clarifying the design concepts and functionality of the assistive technologies. The characteristics of target users also guide the selection of feedback modality and device forms to avoid potential sensory processing disorders (Ringland et al., 2016). Alternatively, customizable multimodal assistive technologies can eventually be developed across different target user populations. Such technologies can be personalized to accommodate various user needs and provide assistance through the most effective modality accordingly (Lopez-Herrejon et al., 2020).

With identified target users, their needs and challenges can be determined through requirement gathering methodologies, including direct observation of target users, and interviews with caregivers or target users. The necessity and importance of target user identification reveal themselves in the user needs identification section. If the technology aims to support autistic adults who have underdeveloped verbal communication skills, the need analysis should be gathered through their caregivers who frequently interact with them. The challenges to be addressed can fall into eight groups of challenges: communication and social skills, vocational rehabilitation, community living skills, home living skills, self-promotion, emotional intelligence, behavior intervention, and health and safety care.

After the requirement gathering process, a multidisciplinary team consisting of researchers, designers, and software development engineers is recommended if allowed by resources to ensure the feasibility and realization of functionality and appropriateness of design elements. We also recommend that emerging technologies, such as natural language processing or facial recognition, can be adopted into the design to facilitate the individualization and generalization of the technology. However, incorporating advanced technologies is not always necessary, and it heavily depends on the target users to be served and their challenges to be addressed.

The evaluation process can be carried out in an early design stage if allowed by resources. Design concepts can be proved by stakeholders through interviews and focus groups, while prototypes should go through well-designed experiments to validate their usability and intervention effectiveness. The results from the evaluation process are able to guide the revision of the designs. As for the summative evaluation, where well-designed experiments are highly recommended, we firmly advocate the inclusion of participants' demographical information (e.g., age, sex, diagnosis) and their levels of independence along with the measuring instruments. This information will significantly support the comparison across studies and avoid repeated efforts on the same set of populations. We also recommend that the evaluation process not only assess the effectiveness of the technologies, but also include the assessment of generalization and maintenance of the skills acquired through technologies. Finally, social validity is also helpful in determining the endpoint of the design iteration.

From a more coherent perspective, there are different models of the software development life cycle (SDLC) that can be applied to assistive technology design. Models with iterative ability are recommended considering that multiple evaluation stages are necessary to deliver useful and inclusive design solutions for autistic adults. The traditional waterfall model or its extension—the V-model—requires structured and sequential design phases (Leau et al., 2012), which might be challenging when designing for autistic adults mainly because the requirements and user needs are explored and eventually finalized during the design process. On the contrary, the iterative model or agile model (R. C. Martin, 2003) might be more applicable in this case due to their flexibility and adaptability. Specifically, the agile model emphasizes that every project is unique and needs to be treated differently with appropriate methods, which largely suits the contexts of designing assistive technologies for autistic adults. Among all the processes, two star-marked processes (Figure 5)–"identify user needs" and "evaluation methodologies"–are two critical steps to developing a well-designed supportive technology, but usually overlooked in existing studies. With the guidelines proposed in the present study, we emphasize the importance of these two steps and advocate including them in design cycles.

4.5 Future Work

It is uncovered from the survey that most of the technologies designed to promote independence for autistic adults in their home living and community living skills recruited participants who had lower than average IQ scores and had limited ability to communicate or perform basic skills. However, this indirectly reveals the lack of research on another portion of autistic individuals who have average or above-average composite IQ scores but confront challenges in daily conversations due to inappropriate social cues they use. Although it seems that autistic adults requiring Level 2 (substantial) or Level 3 (very substantial) support are those in need of assistive technologies the most, autistic adults only requiring Level 1 support are also worth attention. They generally perform well in learning and training but might experience difficulties in social interaction or restricted behaviors. To include a wide range of target users, future work could switch some focus to promoting the communication between conversation partners from a higher level, such as expressing appropriate emotions and generating a proper level of loudness, rather than a lower level of simply producing a speech. This type of research can address the needs of the autistic population actively engaging in social activities, or even another population with suboptimal emotional expression abilities. Besides, future research could also investigate the potential for collaborative assistive technology for communication and social skills, as proposed by a participant in Boyd et al. (2016). Collaborative technology, in general, may support autistic adults to interact with their social networks better, considering its ability to debrief the communicational partners' intentions and feelings toward autistic individuals, or vice versa. Such collaborative technology can also facilitate the public's understanding of the autistic population.

Moreover, there was a lack of research on assistive technologies to promote collaboration among neurodiverse populations in the workplace. While the assistive technologies proposed in the included studies rely on PDAs to provide assistance and improve workers' individual performance, none of them showed interest in investigating and facilitating the collaboration between autistic adults and neurotypical co-workers. In the future, following the guidelines proposed in the previous section, studies can be done to first understand the cooperation pattern between autistic and neurotypical workers and their needs before prototyping assistive technologies or other forms of emerging technologies to promote collaboration quality in addition to individual performance.

While supporting autistic adults in the workplace still gains some attention, research on technologies aiming to improve driving skills in this population has been overlooked for a long time. Driving a vehicle is an important life skill that empowers people with increased mobility and independence. However, individuals on the autism spectrum experienced compromised benefits from driving due to their underdeveloped executive function and motor skills (Brooks et al., 2016; Cox et al., 2017; Cox et al., 2016; Demetriou et al., 2019; Wilson et al., 2018), which are critical for safe driving. Drivers with autism were reported to acquire their license 2.5 years later, drive less frequently, and be less confident about their driving skills than their neurotypical counterparts (Daly et al., 2014). As a consequence of lacking or not being skillful in these critical skills, people on the autism spectrum also face challenges in retaining independence, securing and maintaining employment, and social relationships, which further impacts their vocational and educational opportunities compared to their neurotypical counterparts (Lindsay, 2011, 2017). Although there is growing research investigating the factors affecting the driving behaviors of people on the autism spectrum, no effort has been made to develop systems to improve their driving skills. While researchers are actively contributing to improving the fundamental living experiences of people with autism, we advocate that more research can be conducted to help autistic adults improve their driving skills through emerging technologies.

5 CONCLUSION

The present paper surveyed 32 studies that attempted to design assistive technologies for autistic adults. The included studies all practiced the activities required for a complete product design cycle: from ideation, prototyping, to user evaluation. With strict criteria, we acknowledge that some work-in-progress research studies that attempted to perform a complete product design cycle (e.g., E. Martin et al., 2019) for their proposed technologies can be overlooked, which results in the potential underestimation of the prevalence of well-practiced studies. However, with information from 32 studies, we still acquired substantial findings that can promote the field of assistive technologies for autistic adults. We found that there was a general lack of solid requirements gathering process before developing assistive technologies. *Vocational Rehabilitation* and *Communication and Social Skills* are the two most frequently addressed challenges for the developed assistive technologies. Participants recruited to evaluate those technologies had limited intelligence quotient scores and verbal communication skills. However, although this type of target autistic adults seems to need more support, we suggest that assistive technologies for autistic adults should also assist those with mild characteristics of autism and help them consolidate and enhance their experiences in independent living. Finally, based on the findings from the reviewed paper, we developed an iterative design guideline for assistive technologies for autistic adults. This preliminary guideline inspires future research to focus on requirements-driven designs.

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Biographies

Manhua Wang is a Ph.D. candidate in the Grado Department of Industrial and Systems Engineering at Virginia Tech. Her research interests are Human-Computer Interaction and Human Factors in Systems and Products Design. Her current research focuses on designing user-friendly interfaces for future automobiles and assistive technologies.

Myounghoon Jeon is an Associate Professor in Industrial and Systems Engineering at Virginia Tech. He received his PhD from Georgia Tech. His Mind Music Machine Lab conducts research on HCI/HRI with focus on emotions and sound in the application areas of automotive user interfaces, assistive robotics, and arts in XR.

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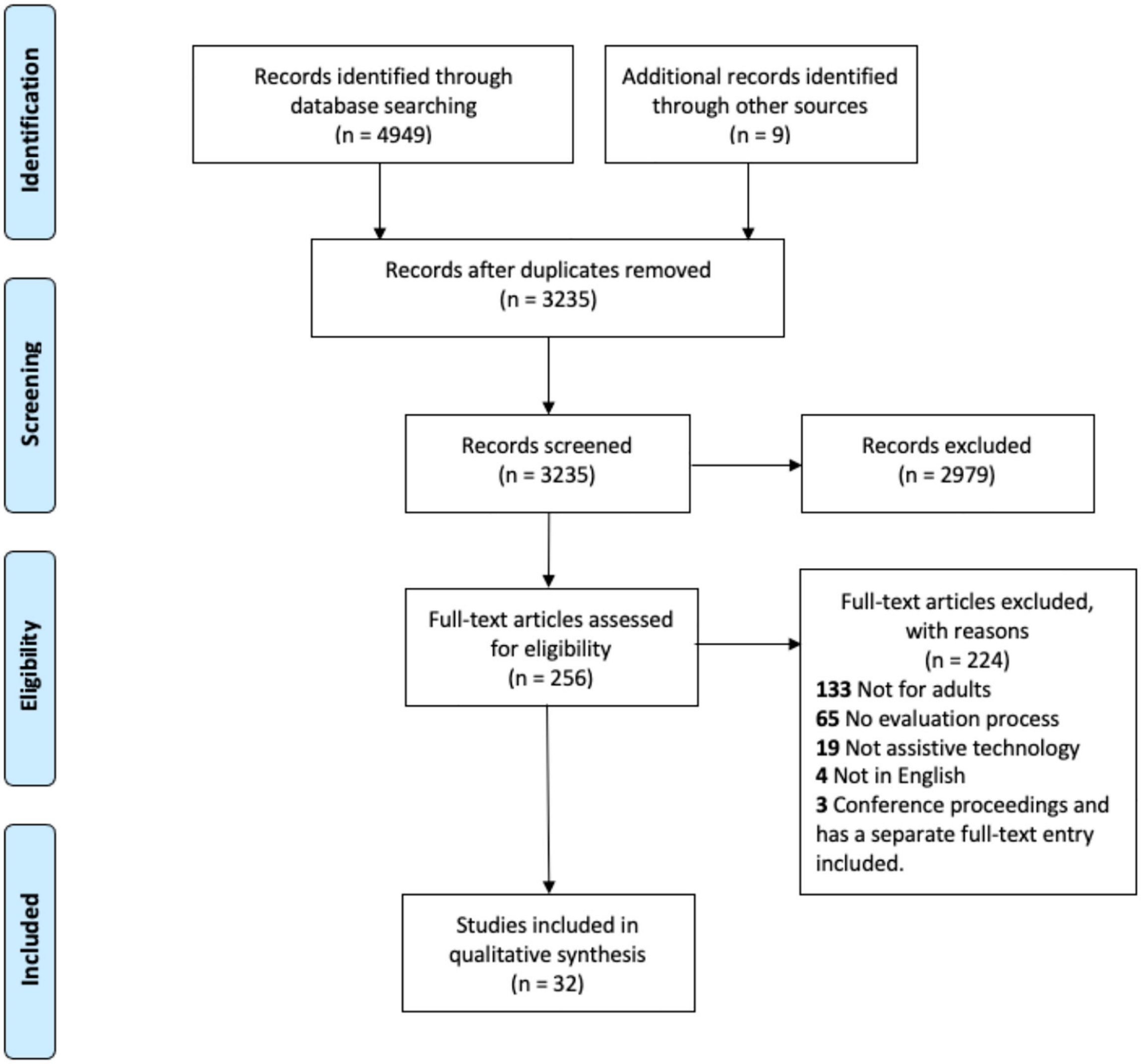

Figure 1.
PRISMA diagram of the screening process (Modified from (Moher et al., 2009))

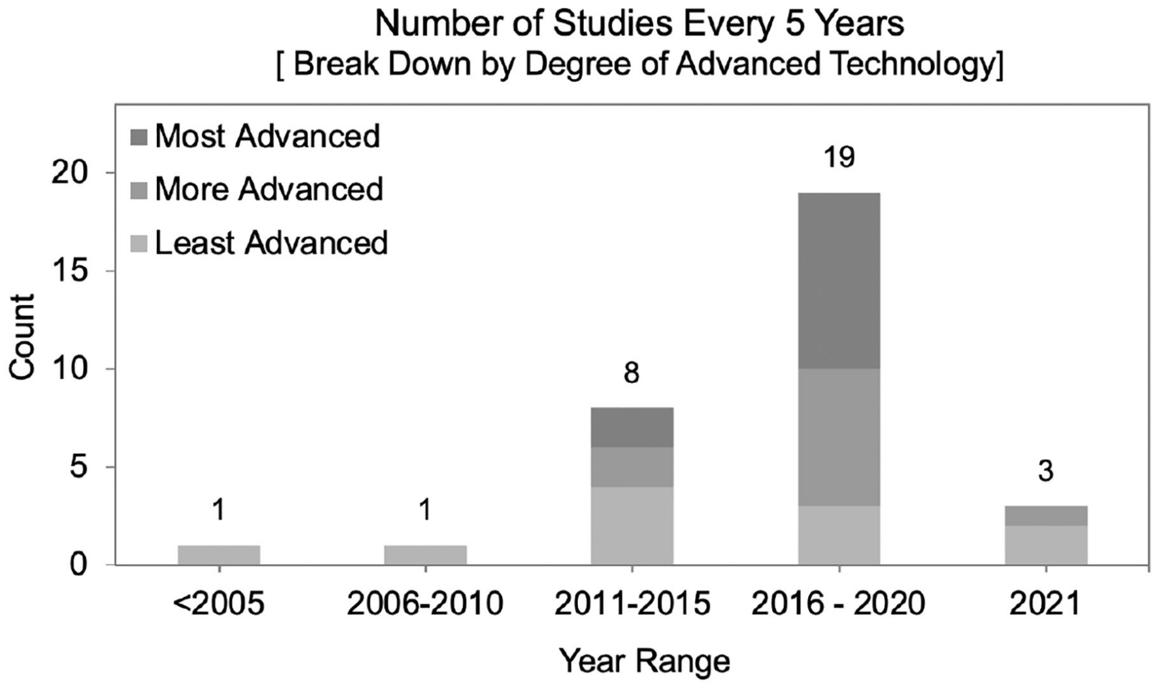

Figure 2.
Trends in Assistive Technology for Autistic adults

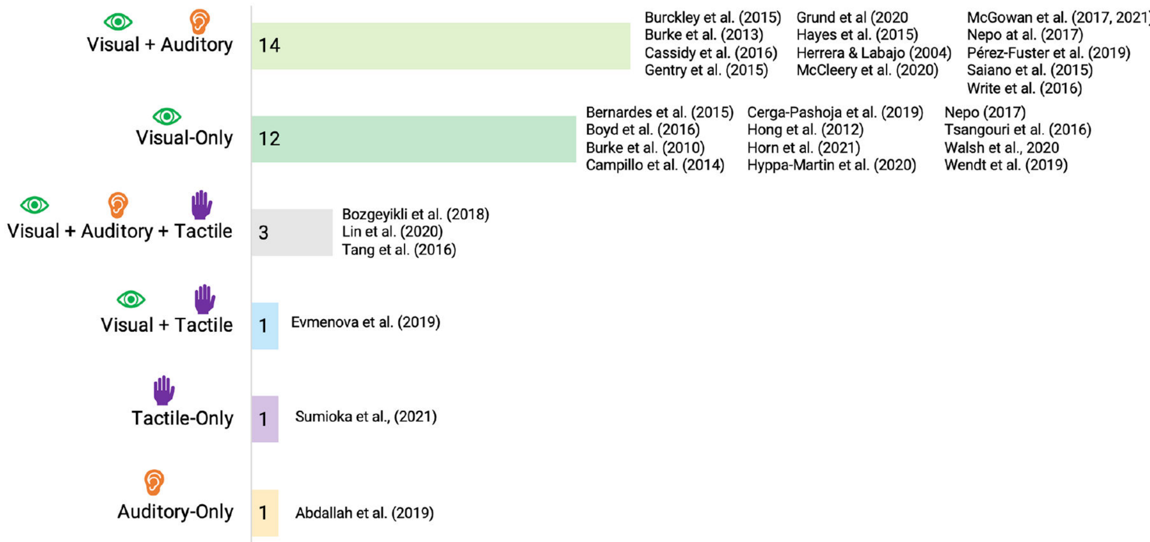

Figure 3.

Interactive modalities used among reviewed assistive technologies.

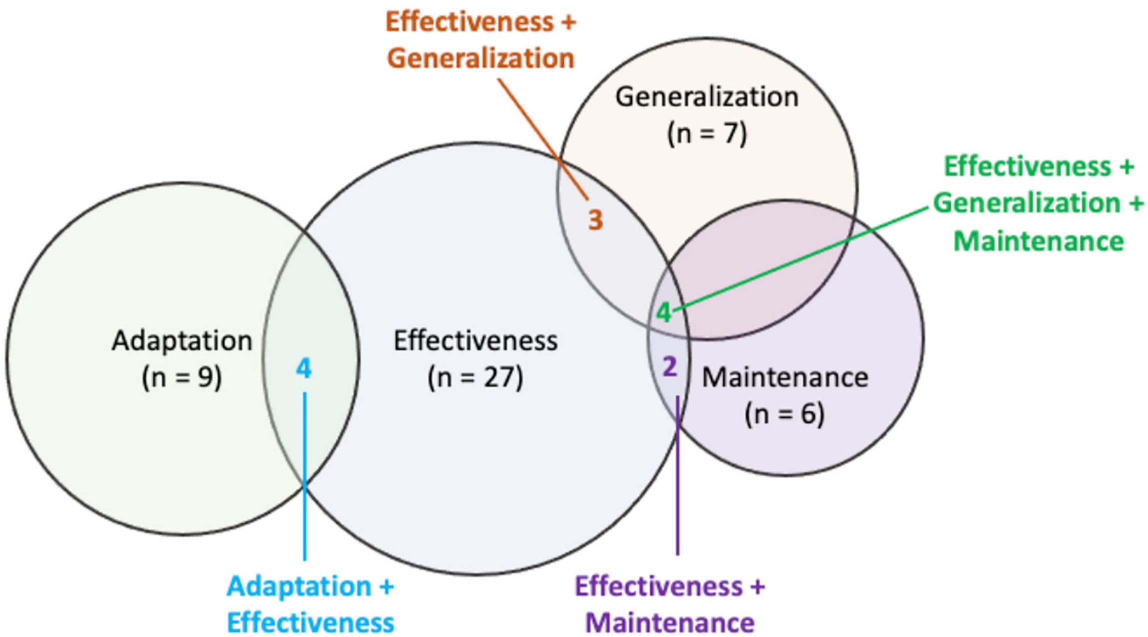

Figure 4.
Intervention stages evaluated by the included study

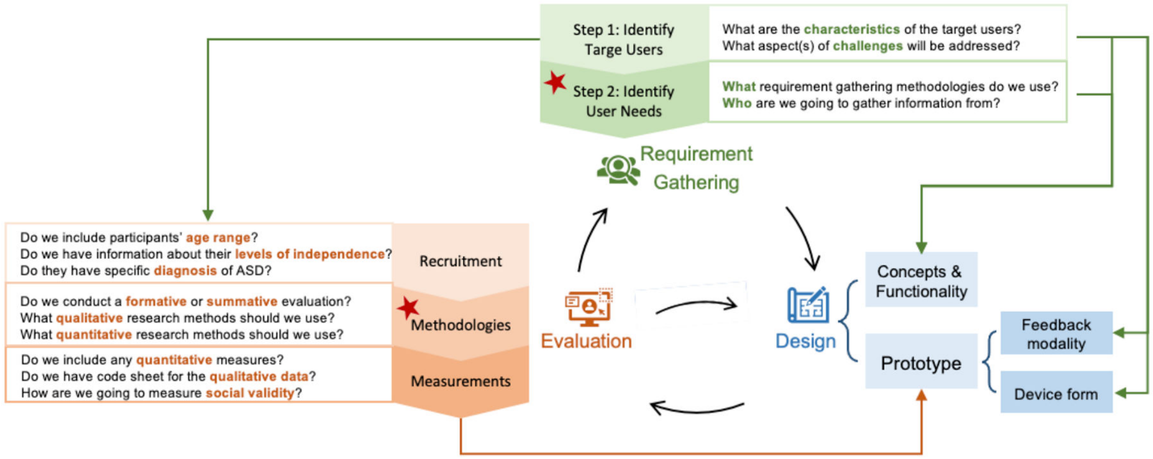

Figure 5.

Iterative design guidelines for assistive technologies for autistic adults

Table 1.

Summary of search strategies for each database used

Database	Search Syntax	# of Results Returned
Web of Science	(TS=(autis*)) AND TS= ((assist* OR adapt* OR help* OR support*) NEAR/5 (device* OR technolog* OR tool*))	1583
EBSCOHost	(TI (autis*) OR AB (autis*)) AND (TI ((assist* OR adapt* OR help* OR support*) N5 (technolog* OR device* OR tool*)) OR AB ((assist* OR adapt* OR help* OR support*) N5 (technolog* OR device* OR tool*)))	1388
Scopus	(TITLE-ABS-KEY (autis*) AND TITLE-ABS-KEY ((assist* OR adapt* OR help* OR support*) W/5 (technolog* OR device* OR tool*)))	1337
IEEE Xplore	((“All Metadata”: autis*) AND ((“All Metadata”: assit* OR adapt* OR help* OR support*) AND (“All Metadata”: technolog* OR device* OR tool*)))	488
ACM Digital Library	(Title:(autis*) OR Abstract:(autis*)) AND (Title:(adapt* OR assist* OR help* OR support*) OR Abstract:(adapt* OR assist* OR help* OR support*)) AND (Title:(technog* OR device* OR tool*) OR Abstract:(technog* OR device* OR tool*))	153

Table 2.

Location distribution of the included citations

Location	Count	Citation
USA	17	(Bozgeyikli et al., 2018; Burckley et al., 2015; Burke et al., 2010, 2013; Evmenova et al., 2019; Gentry et al., 2015; Hayes et al., 2015; Hong et al., 2012; Horn et al., 2021; Lin et al., 2020; Maenner et al., 2021b; McCleery et al., 2020; Nepo et al., 2017; Tang et al., 2016; Tsangouri et al., 2016; Wendt et al., 2019; Wright, 2016)
Multinational	4	(Boyd et al., 2016; Cassidy et al., 2016; Cerga-Pashoja et al., 2019; Hyppa-Martin et al., 2020)
UK	3	(McGowan et al., 2017, 2021; Walsh et al., 2020)
Spain	3	(Campillo et al., 2014; Herrera & Labajo, 2004; Pérez-Fuster et al., 2019)
France	1	(Abdallah et al., 2019)
Italy	1	(Saiano et al., 2015)
Portugal	1	(Bernardes et al., 2015)
Germany	1	(Grund et al., 2020)
Japan	1	(Sumioka et al., 2021)

Table 3.

Design methodologies used in studies with new assistive technologies

		# of Studies	Detailed Information
Requirement Gathering	Interviews	8	Interviews with caregivers (Abdallah et al., 2019; Hong et al., 2012; McGowan et al., 2017, 2021) Interviews with subject matter experts (Boyd et al., 2016; Hayes et al., 2015; Lin et al., 2020) Interviews with target users (Evmenova et al., 2019) Focus group with caregivers (Evmenova et al., 2019) Focus group with target users (Evmenova et al., 2019)
	Observations	2	Observation of target users (Hong et al., 2012; Tang et al., 2016)
	Not specified	9	(Bernardes et al., 2015; Burke et al., 2013; Cassidy et al., 2016; Cerga-Pashoja et al., 2019; Grund et al., 2020; Herrera & Labajo, 2004; Nepo et al., 2017; Pérez-Fuster et al., 2019; Saiano et al., 2015)
Design Principles		4	User-Centered design approach (Abdallah et al., 2019) Design guidelines developed from requirement gathering (Boyd et al., 2016) Universal design principles (Burke et al., 2013) * Design-based research framework (Evmenova et al., 2019)

*This study did not specify any requirement gathering methodology

Table 4.

Device forms of assistive technologies (multiple-device forms exist for some technologies)

Personal Digital Assistant (PDA) (n = 19)	Handheld Device (e.g., smartphones, iPod)	(Abdallah et al., 2019; Burke et al., 2010; Campillo et al., 2014; Gentry et al., 2015; Hayes et al., 2015; Hong et al., 2012; Horn et al., 2021; Hyppa-Martin et al., 2020; McCleery et al., 2020; Nepo et al., 2017; Pérez-Fuster et al., 2019; Tang et al., 2016)
	Tablet (e.g., iPad)	(Burckley et al., 2015; Burke et al., 2013; Campillo et al., 2014; Maenner et al., 2021b; McCleery et al., 2020; Walsh et al., 2020; Wendt et al., 2019)
	Smartwatch	(Evmenova et al., 2019; Wright, 2016)
Virtual Environment (n = 8)	AR	(Boyd et al., 2016; Grund et al., 2020; Lin et al., 2020; Wright, 2016)
	VR	(Bernardes et al., 2015; Bozgeyikli et al., 2018; McCleery et al., 2020; Saiano et al., 2015)
Computer-Based System (n = 6)		(Campillo et al., 2014; Cassidy et al., 2016; Cerga-Pashoja et al., 2019; McGowan et al., 2017, 2021; Tsangouri et al., 2016)
Physical Object (n = 4)		(Grund et al., 2020; Herrera & Labajo, 2004; Pérez-Fuster et al., 2019; Sumioka et al., 2021)

Table 5.

Synthesis of targeted needs and use contexts in the included studies

Targeted Needs	Total Count	Use Context (study count; multiple-use contexts existed)				
		Home	Day-to-day activity	Training	Workplace	Therapy
Vocational rehabilitation	9	1		8	8	
Communication and social skills	8	1	3	3		2
Community living skills	6		4	2		
Emotional intelligence	4	2	2	2		
Home living skills	4	4				
Self-promotion	4	1	1		2	2
Behavior intervention	1		1			
Health and safety	0					

Table 6.

Evaluation methodologies in included articles

User studies (N = 6)	Observation	(Abdallah et al., 2019; Boyd et al., 2016)
	Usability testing	(Evmenova et al., 2019; Grund et al., 2020; Herrera & Labajo, 2004; Tang et al., 2016)
Experimental studies (N = 26)	Between groups designs (n = 6)	Neurotypical vs. autism: (Bernardes et al., 2015; Bozgeyikli et al., 2018; Cassidy et al., 2016) Treatment vs. control OR treatment1 vs. treatment 2: (Gentry et al., 2015; Hayes et al., 2015; McCleery et al., 2020)
	SCEDs (n = 18)	Pre-experimental (AB) design: (Campillo et al., 2014; McGowan et al., 2017, 2021; Saiano et al., 2015; Tsangouri et al., 2016) Reversal (ABAB) design: (McGowan et al., 2021; Pérez-Fuster et al., 2019) Multiple-baseline design: (Burke et al., 2010, 2013) Multiple-probe design: (Burckley et al., 2015; Horn et al., 2021; Hyppa-Martin et al., 2020; Maenner et al., 2021b; McMahon et al., 2016; Nepo et al., 2017; Wendt et al., 2019) Alternating treatment design (ATD): (Boyd et al., 2016; Walsh et al., 2020)
	Mixed design (n= 2)	(Cerga-Pashoja et al., 2019; Sumioka et al., 2021)
Interviews (N = 4)	Semi-structured interview	(McGowan et al., 2021)
	Structured interview	(Boyd et al., 2016)
	Focus group	(Hong et al., 2012)
	Not specified	(Lin et al., 2020)

Table 7.

Synthesis of participants' characteristics in included studies

Targeted Challenges	IQ Score		Age Range	Sex (count)	
	Score Range	Measurement		M	F
Vocational rehabilitation (N = 9)	70–121 (Burke et al., 2010, 2013)	Kaufman Brief Intelligence Test-Second Edition	18 – 28	10	0
	59 – 60 (Walsh et al., 2020)	Stanford Binet, Fifth Edition	20 – 21	2	1
	N.S. (Bozgeyikli et al., 2018; Gentry et al., 2015; Grund et al., 2020; Hayes et al., 2015; Herrera & Labajo, 2004)	-	17 – 60	73*	14*
Communication and social skills (N = 8)	"very-low range" (Hyppa-Martin et al., 2020)	Kaufman Assessment Battery for Children	19	1	0
	75 – 132 (McCleery et al., 2020)	Wechsler Abbreviated Scale of Intelligence - Second edition (WASI-II)	12 – 38	52	8
	N.S. (Boyd et al., 2016; Lin et al., 2020; McGowan et al., 2017, 2021; Nepo et al., 2017; Wendt et al., 2019)	-	14 – 41	20*	6*
Community living skills (N = 6)	54 (Burckley et al., 2015)	WASI-II	18	0	1
	56 – 97 (Saiano et al., 2015)	Wechsler Adult Intelligence Scale-Revised (WAIS-R)	19 – 44	7	0
	57 – 64 (Wright, 2016)	Wechsler Intelligence Scale for Children-III	18 – 21	4	2
	N.S. (Bernardes et al., 2015; Hong et al., 2012; Horn et al., 2021)	-	18 – 35	17	3
Emotional Intelligence (N = 4)	35 – 38 (Campillo et al., 2014)	N.S.	19 – 29	2	1
	Mean (SD) = 87.7(14.1) (Sumioka et al., 2021)	N.S.	20.3 (2.9)	21	3
	N.S. (Cassidy et al., 2016; Lin et al., 2020; Tsangouri et al., 2016)	-	18 – 36	17*	23*
Home living skills (N = 4)	36 – 47 (Maenner et al., 2021b)	Stanford Binet, Fifth Edition	35 – 45	4	2
	N.S. (Abdallah et al., 2019; Pérez-Fuster et al., 2019; Tang et al., 2016)	-	19 – 37	15	6
Self-promotion (N = 4)	75 – 168 (Cerga-Pashoja et al., 2019)	N.S.	22 – 48	114	39
	N.S. (Evmenova et al., 2019; McGowan et al., 2017, 2021)	-	18 – 28	15	8
Behavior intervention (N = 1)	35 – 38 (Campillo et al., 2014)	N.S.	19 – 29	2	1

N.S. = Not Specified;

*These counts do not include data from Grund et al. (2020), Lin et al. (2020), or Tsangouri et al. (2016) because gender information was not specified.

Table 8.

Participants' information in between groups experimental studies (Autism vs. Neurotypical)

	Age Range		Sex (Male: Female)	
	Autism	**Neurotypical**	**Autism**	**Neurotypical**
(Bernardes et al., 2015)	Mean (SD) = 32.2 (4.0)	Mean (SD) = 30.7 (6.2)	3:2	3:2
(Bozgeyikli et al., 2018)	20 – 41	21 – 50	7:2	10:0
(Cassidy et al., 2016)	Mean (SD) = 40.9 (13.2)	Mean (SD) = 43.7 (14.8)	17:23	7:32

Table 9.

Summary of dependent measures used to assess the assistive technology

Category	Specific measures
Quantified performance (n = 26)	Task performance: • Percentages of steps correctly completed without prompting (Burckley et al., 2015; Burke et al., 2010, 2013; Horn et al., 2021; Wright, 2016) • Task duration (Maenner et al., 2021b) • Task completion (Burke et al., 2013; Grund et al., 2020; Herrera & Labajo, 2004; Maenner et al., 2021b; Tang et al., 2016) • Task-specific (Bozgeyikli et al., 2018; Cassidy et al., 2016; Cerga-Pashoja et al., 2019; Hyppa-Martin et al., 2020; Saiano et al., 2015; Tsangouri et al., 2016; Walsh et al., 2020) Number of occurrences or frequency of behaviors: • Vocal requests (Abdallah et al., 2019; Nepo et al., 2017; Wendt et al., 2019) • Expected behaviors after intervention (Hayes et al., 2015; McGowan et al., 2017, 2021) • External prompts or support (Gentry et al., 2015; Pérez-Fuster et al., 2019) • Challenging behaviors related to anxiety (Campillo et al., 2014) Observed performance (Boyd et al., 2016; Hayes et al., 2015; McGowan et al., 2017, 2021)
Questionnaires for participants (n = 18)	User satisfaction and perception (Bernardes et al., 2015; Boyd et al., 2016; Bozgeyikli et al., 2018; Burke et al., 2010; Cassidy et al., 2016; Evmenova et al., 2019; Herrera & Labajo, 2004; Hong et al., 2012; Lin et al., 2020; Tang et al., 2016; Tsangouri et al., 2016; Walsh et al., 2020) Skill acquisition assessment questionnaire (Saiano et al., 2015) Self-reported text complexity (Cerga-Pashoja et al., 2019) Universal Design Performance Measure for Productivity (Burke et al., 2013) System Usability Scale (McCleery et al., 2020) Communicative Responses and Acts Score Sheet (McGowan et al., 2021)
Questionnaires for caregivers (n = 6)	Skill transfer questionnaire (Saiano et al., 2015) Post-study behavioral change survey (McGowan et al., 2017) User satisfaction and perception (Abdallah et al., 2019; Burke et al., 2010; Hong et al., 2012) Post-study behavioral change survey (McGowan et al., 2021)
Social validity (n = 7)	Treatment Evaluation Inventory-Short Form (TEI-SF) (Burke et al., 2013) A treatment acceptability rating form modified from Reimers & Wacker (1988) (Wendt et al., 2019) Self-developed survey (Burckley et al., 2015; Horn et al., 2021; Maenner et al., 2021b; Walsh et al., 2020; Wright, 2016)