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Voice assistant technology applied to populations with developmental and physical disabilities

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ABSTRACT

Emerging assistive technologies (AT), such as voice assistants (VA), impact the citizenry and organisations. Amongst those affected, there is a group of people with developmental and physical disabilities that have been impacted the most. As the use of technology evolves, more studies analysing the impact of VA on these populations are emerging. However, there is still a dearth of studies congregating results systematically, in which it would be possible to understand the impact of VA technologies on different contexts. Thus, our study aims to understand the applicability and impact of VAs on the lives of people with disabilities and the perspectives of this emerging AT. Drawn on a rigorous systematic literature review using the PRISMA protocol, we included 68 articles for analysis after applying the inclusion and exclusion criteria. We identified seven intertwined themes related to the benefits and challenges of VA technologies. The emergent benefits are the impact on users' ecosystem and well-being and economic and social benefits; conversely, the challenges are inherent issues related to technology, financial and social challenges. We contribute to theory and practice by understanding the impact of VAs on populations with disabilities' ecosystem and well-being at the micro, meso and macro-levels of the phenomena.

HIGHLIGHTS

- VA technology transforms the way people with disability interact in their ecosystem
- VA technology positively impacts people with disabilities' well-being and ecosystem
- VA issues are related to data privacy and technology accessibility
- Benefits and challenges of the VA adoption touches the micro, meso and macro-levels of the ecosystem
- Performance analysis, diverse populations and understanding of social aspects, are the trending topics for future research

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Assistive technology; developmental disability; disabilities; people with disability; physical disability; voice assistant

1. Introduction

The technologies used today are offering more efficient ways to perform many day-to-day activities (Hedman, Lindqvist, and Nygard 2016). For example, the emergence of Artificial Intelligence (AI) and the Internet of Things (IoT) supported the development of various types of equipment that facilitate human life, such as virtual reality, autonomous cars, simulations, and particularly, voice assistants (VA) (cf. Vollmer Dahlke and Ory 2017; Lillywhite and Wolbring 2021; McLean and Osei-Frimpong 2019). Technological evolution has enabled many tasks to be done more easily and more conveniently, such as smart homes, where the equipment (or smart equipment) is connected and automated and responds to people's needs in an intelligent environment, promoting a better quality of life (Busatlic et al. 2017).

One of these types of smart home automation equipment is the VA (also known as virtual personal assistant, digital assistant or intelligent personal assistant). This equipment is an artificial intelligence application that helps people perform numerous day-to-day activities and tasks (Brill, Munoz, and Miller 2019), such as sending messages and setting times, communicating with other connected services, such as streaming of music and video, and residential automation activities, like controlling smart home applications (e.g. TV and lights), and being used as assistive technology (AT) through the interpretation of the human voice (e.g. Hoy 2018; Budzinski, Noskova, and Zhang 2019; Lee,

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Lee, and Sheehan 2020). The ATs are any technologies or equipment used to improve the functional capabilities of people and promote independence and well-being (Darcy, Green, and Maxwell 2017; McNicholl et al. 2021). And in this context of use, the technology of VAs is mentioned as AT by several authors (e.g. Mechling, Gast, and Seid 2009; Portet et al. 2013).

For people with disabilities, the VA has a significant impact on their ecosystem (e.g. friends, family, organisations and third parties), offering control over the home environment, independence, and increased well-being. Such impact on people with disabilities motivates our research to investigate this population. One might argue that this is also a common impact on people without restrictions, and we agree with this argument; however, people who are developmentally and physically restricted are the ones who usually rely on family or social care to perform their activities of daily living (ADLs), and therefore, whom could benefit the most from ATs (e.g. Budzinski, Noskova, and Zhang 2019; Leite, Hodgkinson, and Volochtchuk 2023). For example, Noda (2018) conducted a study on the use of the VA by disabled people, who began to control the home environment by voice command, and this increased the independence and quality of life of these individuals.

Because VA is an emerging AT that has evolved rapidly, many studies were developed to understand the impact of VAs on the ecosystem of populations with disabilities (cf. Lee, Lee, and Sheehan 2020; Vieira, Leite, and Volochtchuk 2022). In this vein, Gentry et al. (2010), described the use of personal digital assistants to help students with autistic spectrum disorder in everyday activities and concluded that the level of satisfaction of students in carrying out day-to-day tasks increased, as well as the independence in performing these tasks. Despite the advances in research in this area of VA technology for people with disabilities and the maturity of the available studies, the literature still presents a shortage of studies that discuss the results and impacts of this technology on the lives of this populations in a unified way, with some studies only descriptive and focused on the features and characteristics of the equipment (e.g. Carver et al. 2016; Labonnote and Høyland 2017; Hoy 2018). In addition, there are calls for further research including the use of ATs (e.g. VAs) by disabled people and how this type of technology has contributed to improving the collective and individual well-being of these people (e.g. Chang, Omery, and Mayo 2003; Anderson, Nasr, and Rayburn 2018; Breslin, Shareck, and Fuller 2019; Masina et al. 2020; Ostrom et al. 2021; Smith et al. 2021; Leite, Hodgkinson, and Volochtchuk 2023; Vieira, Leite, and Volochtchuk 2022). Finally, we believe that new studies, such as those we propose in this research, can contribute to legislators in order to create regulations to extend access to this type of AT for people with different types of disabilities.

Thus, our study aims to perform a thorough analysis of the existing literature and thus understand the applicability and impact of VAs on the lives of people with disabilities and the perspectives of this emerging AT. To this end, we derived four research questions (RQ) that will guide our study:

RQ1. What is the impact of the use of VAs on the ecosystem of people with disabilities?

RQ2. What is the current outline of the VA literature for people with disabilities?

RQ3. What challenges does VA technology face to become a common AT for people with disabilities?

RQ4. What are the research protocols, perspectives, and trends for using VA technology with people with disabilities?

To answer these research questions, we used a Systematic Literature Review (SLR) (Tranfield, Denyer, and Smart 2003) guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Moher et al. 2009).

The structure of this article consists of the following: introduction, where we present an overview of the literature and the justification of the systematic literature review. A section addressing the voice assistant technology background. A methodological section describing how we conducted this literature review. The results from the descriptive and thematic analysis, discussion, and conclusion of the study.

2. Background on voice assistant technology

Voice assistants are artificial intelligence-based tools that offer assistance in various daily activities and tasks (Brill, Munoz, and Miller 2019). VAs respond to voice commands to perform specific tasks according to people's needs, and as they can be used to improve people's practical skills and encourage their autonomy and quality of life, they are considered an assistive technology by numerous authors (Mechling, Gast, and Seid 2009; Portet et al. 2013; Darcy, Green, and Maxwell 2017; McNicholl et al. 2021).

Some of the most common examples of VAs available on the market are Alexa (Amazon), Cortana (Microsoft), Siri (Apple) and Google Home (Hoy 2018; Budzinski, Noskova, and Zhang 2019; Lee, Lee, and Sheehan 2020). The first release of a digital assistant was made by Apple in 2010, with the Siri software; this led to a revolution in the VA market (Hoy 2018; Lee, Lee, and Sheehan 2020). The second digital

assistant was released by Microsoft in 2013 called Cortana (Hoy 2018). In 2014, Amazon's Alexa device was launched in the market, the first with a speaker system outside the cell phone and a specific voice assistant device (Amazon Echo), which can play music, set alarms, and connect with other smart devices. Two years later, Google launched the Google Home VA device, and in 2018, Apple released the Apple HomePod device (Lee, Lee, and Sheehan 2020).

Currently, VAs are applied in several spaces, such as households (Smith et al. 2021), schools (Mechling, Gast, and Seid 2009; Gentry et al. 2010) and public spaces (Masina et al. 2020), and can be used for the most diverse tasks. For example, in library research activities (Zimmett 2020), quick access to medical information (Lindquist et al. 2008), as well as use in smart homes (Busatlic et al. 2017). VAs in homes have been proven effective for populations without physical restrictions (Vieira, Leite, and Volochtchuk 2022). Manaris, Macgyvers, and Lagoudakis (2002) developed a voice interface to facilitate the use of computers and mobile devices by people with motor disabilities and showed that these people could complete their tasks much faster. However, the applications of such technology can also benefit those with different types of limitations (Vollmer Dahlke and Ory 2017; Lynch et al. 2022). For example, elderly people with mobility problems, degenerative diseases that affect people's functional capacity, those affected by severe brain accidents, and people with some kind of developmental or physical disabilities (Darcy, Green, and Maxwell 2017; Barata et al. 2018). According to the CDC (2023), the latter is a group of conditions due to an impairment in physical, learning, language, or behaviour areas that makes it more difficult for the person with the condition to do certain activities and interact with the world around them. In developmental disabilities, autistic spectrum disorder is the most common cause, whereas body impairments are the leading cause of physical disabilities. For this study and to simplify the understanding of the population target, we refer to people with developmental or physical disabilities as 'people with disabilities'.

The literature mentions numerous benefits of using VAs by people with disabilities. For example, increased independence (Darcy, Green, and Maxwell 2017; Borade, Ingle, and Nagarkar 2021), social involvement (Söderström and Ytterhus 2010; Vollmer Dahlke and Ory 2017), improved quality of life (Chang, Omery, and Mayo 2003), and increased ease of mobility (Borade, Ingle, and Nagarkar 2021). Conversely, the literature also mentions challenges in the use and access of this technology, such as security and privacy-related risks (Lindquist et al. 2008) and the high cost (cf. Lindquist et al. 2008; Vollmer Dahlke and Ory 2017).

These are some illustrative examples of the use of VAs as ATs, focusing on their utilisation by individuals with disabilities. In view of these examples, the great potential of this technology and the need for studies that understand the applicability and impact of VAs in the lives of people with disabilities, as well as the perspectives of this emerging technology, can be observed. Therefore, our study aims to address this void in the literature and contribute to this emergent area of ATs in special VA applications for people with disabilities.

3. Methodology

In this section, we present the description of the methodology of the SLR and procedures used for the data analysis of the articles found. SLR is a methodology used to obtain secondary qualitative data in a more structured way by creating a research protocol which uses a replicable, scientific and transparent process (e.g. Tranfield, Denyer, and Smart 2003). Therefore, to ensure research trustworthiness, we used the PRISMA protocol (e.g. Moher et al. 2009) to conduct and report the SLR, and the procedures were registered in Figure 1. Additionally, to support a structured data collection report, we applied the three phases (planning, conducting, and reporting and dissemination) from Tranfield, Denyer, and Smart (2003). When applied with the PRISMA protocol, the three phases improve the quality of the review process, synthesising the research in a systematic, transparent and reproducible way (e.g. Kranzbühler et al. 2018).

The planning phase defines the purpose of the review and writing of the research protocol as a stage of definition, clarification and refinement (Guckenbiehl, de Zubielqui, and Lindsay 2021). In the research protocol based on PRISMA, we describe the main elements of the search and collection structure of articles, for example, the inclusion criteria (e.g. only articles containing the selected keywords and database, and in English), and the exclusion criteria (e.g. no grey literature, and articles about VA that do not relate to the study's aims) criteria. The protocol is a plan that protects objectivity. It provides explicit descriptions of the measures to be taken, containing information on the specific issues addressed by the study and the search strategy for identifying relevant studies (Tranfield, Denyer, and Smart 2003; Ninomiya et al. 2022).

To access the most relevant secondary data in the literature, we aimed to collect data from peer-reviewed journals, avoiding 'grey literature'. The databases for searches of articles were selected to cover a

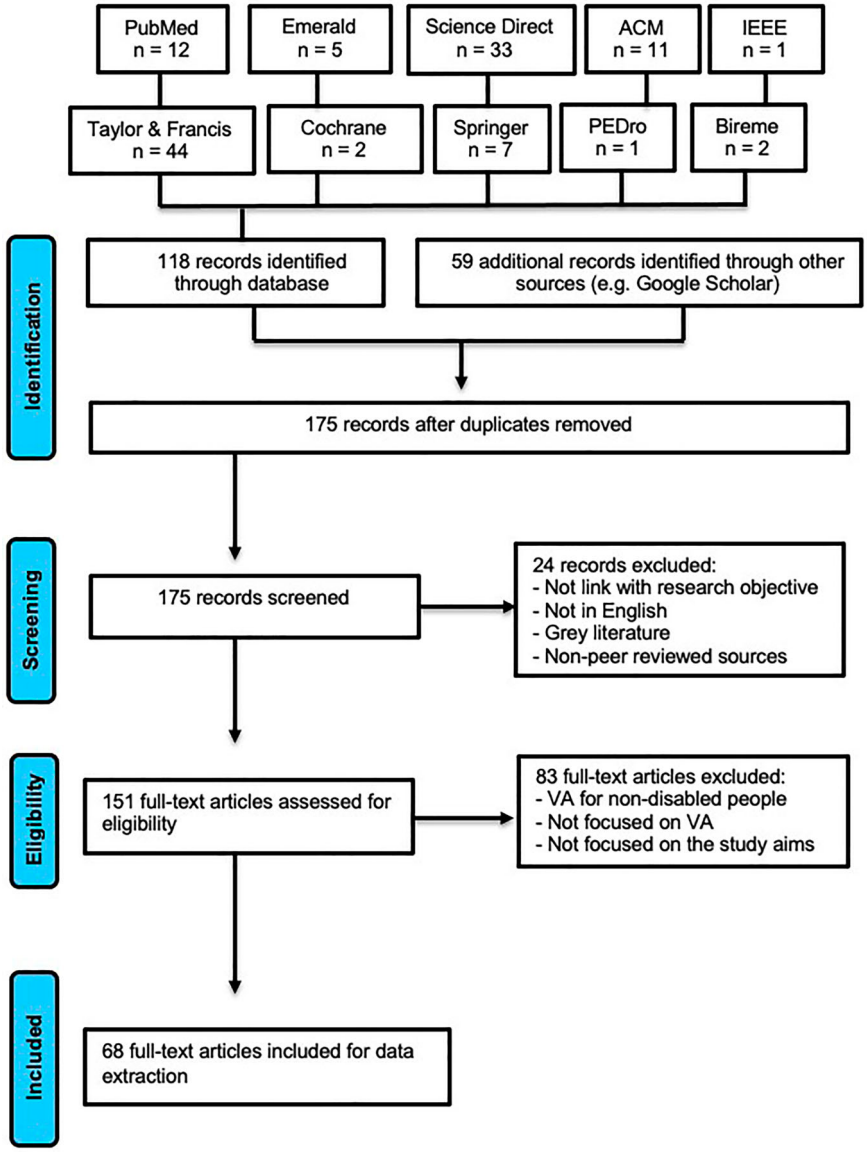

Figure 1. Systematic literature review: PRISMA flowchart.

comprehensive database of articles as a reference in academic searches and in line with the review's objective. In addition, tests were performed to collect articles in other databases; however, the ones displayed in figure 1 were those that returned the studies. A final search was performed to cross-reference articles in Google Scholar to ensure the inclusion of all articles related to the analysis. This database is used for a final search because Google congregates different databases and might reach articles not captured in the first search in the original database.

The keywords were defined based on several terms that referred to 'voice assistants' and were found in the literature presented in the introduction of this article, thus ensuring greater inclusion of articles that studied this technology. The keywords are: 'voice assistant', 'virtual personal assistant', 'intelligent personal assistants', 'virtual assistant', 'personal digital assistant', and 'smart speaker'. We also used the keyword 'assistive technology', but after the pilot, we concluded that this word is generic and would not show only studies about VAs but all ATs available, which is out of the scope of our study.

These keywords were related to associated words (secondary words) to achieve the highest possible number of combinations for research. The associated keywords were also defined based on the literature. They were related to the health condition of the population target of the study, which includes: 'autism', 'autistic spectrum', 'brain injuries', 'disabled people', 'developmental disability', 'inclusiveness', 'impaired people', 'people with disabilities', 'person with disability', 'people

with special needs', 'physical disability', 'physical impairments', and 'reduced mobility'.

In the search process, each of the main keywords was combined with each of the associated words, using the Boolean operator 'AND'. For example, the keyword 'voice assistant' was cross-checked with all associated words (e.g. voice assistant AND physical disability), and so on. This process was tested in a pilot search in databases, and they returned a high volume of articles. Finally, the search period covered articles published up to January 2023.

Boolean operators are operators used to combine keywords and associated terms in the SLR. In addition to the AND operator, other operators were tested during this phase. The authors tested the OR operator (e.g. voice assistant OR physical disability), and this operator returned very broad results as it also returned articles only about 'voice assistant' or only about 'physical disability', for example. Another test was conducted using the wildcard (*) operator, which represents any combination of characters within a search term, but it did not influence the results obtained during the article collection phase.

3.1. Data collection

The second stage is to conduct the review, and the collection of articles used for the analysis was done as follows: first, articles were collected that contained in the title, keywords or in the abstract one or more associated and keywords defined by the authors. This selection led to the collection of 175 articles. After that, the authors applied the exclusion criteria in two phases. The first phase of the application of the exclusion criteria discarded all articles that were characterised as grey literature (non-peer reviewed journals and conferences) and not in English, which is a quality filter of the studies (e.g. Bornmann and Daniel 2008) where we excluded 24 articles, resulting in 151 articles available for the eligibility phase. The second phase of the application of the exclusion criteria (eligibility) was the deletion of articles that were not related to the objective of the research, for example, VAs not focused on people with disabilities or not related to the aims of the study, which led to the exclusion of 83 articles, leaving 68 articles for analysis in our study.

The articles used in this study were organised in a database in an MS Excel table to structure the data used in the analysis of results, and this table is called the 'data-extraction form'. Tranfield, Denyer, and Smart (2003, 216) define this form as a spreadsheet that 'often contain general information (title, author, publication details), study features and specific information (details and methods) and notes on emerging themes coupled with details of synthesis', which is also recommended by the Cochrane Collaboration. In our data-extraction form, we organised the data, such as title, author, year, country of the study, journal of publication, methodology adopted, and VA application area. Furthermore, we mapped other elements aligned with the aims of our study, such as challenges and limitations of using the VA, protocols applied and suggestions for future research. Finally, this table contributes to answering the research questions since it presents a structured and visual representation of the collected data and acts as a chronological account of the analysis process of the collected articles.

3.2 . Data analysis

The third and final stage of the SLR approach is the reporting and disseminating of results. The data analysis followed the suggestion of Tranfield, Denyer, and Smart (2003) and was carried out in two parts: descriptive analysis and thematic analysis. In the descriptive analysis, we present an outline of the literature; this analysis enables the identification of relevant quantitative data, such as the increase in the number of publications on the subject from a given year onwards or in which country there are more publications on the subject in question.

In relation to the thematic analysis, it is more prescriptive and much used in the qualitative field since it allows the researcher to organise the data studied. This analysis also allows the researcher to be close to the data studied, with great proximity to the context and details. Thus, standards are sought in the data from the articles collected, and themes are defined to represent them (Braun and Clarke 2006). The thematic analysis was conducted adopting the six steps suggested by Braun and Clarke (2006, 87): (1) familiarising with data, (2) constructing initial codes, (3) reading and searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report or findings. Since the thematic analysis enables the researcher's approach to the data, context and details, it has become a valuable analysis to understand the implications, benefits and challenges of using the VA by people with disabilities and emerging themes for future research.

Finally, the search for the articles was conducted by the second and third authors, and the first author conducted the data extraction. To establish data analysis trustworthiness and reliability, we followed similar procedures suggested by Hu et al. (2015) when carrying out SLR, and we formed a review panel to audit the data

extraction and thematic analysis. All authors of the article, who individually analysed the data, formed the panel; furthermore, an external member (an academic specialist in thematic analysis) also audited the codes and themes, crosschecked and helped to confirm the results. When contradictions were found, the panel held meetings to make changes and reach an agreement that would benefit the study.

4. Findings from the descriptive and thematic analysis

This search section presents the results based on the extraction form. In the first step, we present the descriptive analysis and then the thematic analysis and its implications.

4.1. Descriptive analysis

This analysis presents an outline of the literature related to the use of the VA by people with disabilities, which provides a response to our RQ2. For example, information on the number of articles published in a timeline, geographic regions where these studies were carried out, methodologies used by the articles, main areas of application of the voice assistants, disability or health condition studied by the articles analysed and main journals where these articles were published. This information is important to assist in identifying patterns, trends and opportunities for developing new research in this area.

Our analysis presents the distribution of articles published on the subject in the last 30 years (Figure 2). It is important to point out that only for this chart we excluded the articles published in the year 2023 because it was the year of the data collection and which ended in the month of January; this could present a difference in the actual evolution of the publications. We realise that there has been an increase in the number of publications since 2017, and a possible justification is the expansion of applications and use of voice assistants by people with disabilities, the reduction in equipment prices (greater accessibility), maturity of the technology, as well as the launch of new devices, for example, Google Home. Another relevant factor is that VAs first entered the market in order to facilitate daily tasks, and after that, they were implemented as assistive technology to support groups of disabled people (e.g. Hoy 2018; Apergi et al. 2021). A sharp drop in publications was noticed in 2019; conversely, there was a significant increase in 2020 ($n = 11$), which we consider the peak of publications as in the following years the publications started to decrease.

Another element that we analysed about the publications was the international journals of publication of the articles analysed, and we found 46 different journals that published articles on the subject of our research. Despite the variety of journals in the results found, our analysis shows that there is a concentration of 33% of the publications in 6 journals (see Appendix A).

To understand where the main studies on the use of VAs by people with disabilities are carried out, we conducted an analysis of the geographical distribution of the publications (these numbers are based on the region where the study was conducted and not where the article was published). In order for us to have a grouping of these countries by region, we have grouped the articles in their respective continents. Figure 3 shows

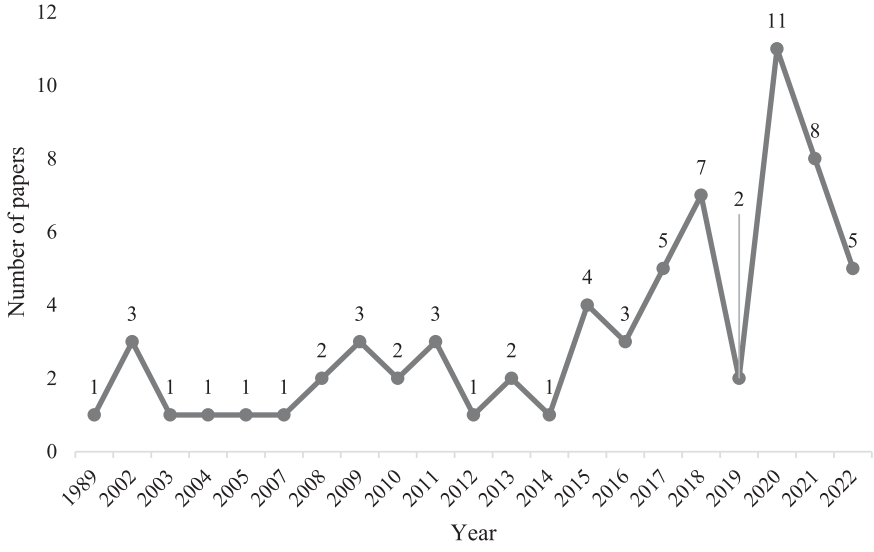

Figure 2. Papers published by year.

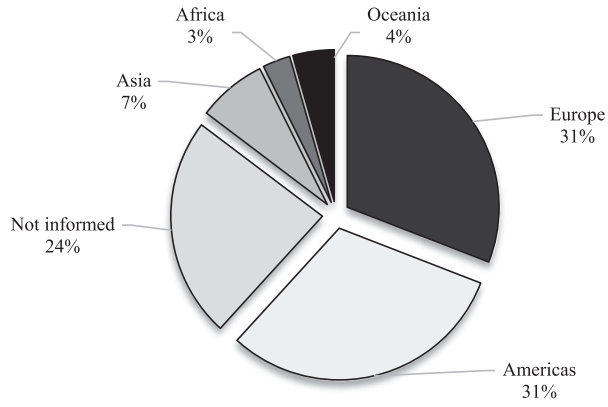

Figure 3. Papers by continent.

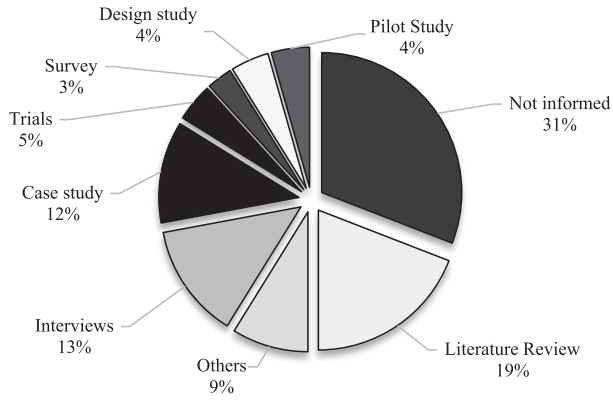

Figure 4. Methodologies.

that the largest number of research on the subject was carried out in the continents of the Americas (n = 31%) and Europe (n = 31%). From these studies, under a deeper look, the countries of these continents that have published the most were the United States and the United Kingdom. We believe that the largest number of studies in these countries is justified by being two developed countries that are amongst the five largest economies in the world, thus having greater access to resources and research. In addition, we also believe that the largest number of articles published on the subject in the United States has an influence on the location of VA developer companies – Apple, Google, Microsoft and Amazon, which are in this country. For example, Smith Myles, Ferguson, and Hagiwara (2007) evaluated the effectiveness of a voice assistant to assist in homework lessons of students with Asperger syndrome, in high school in the United States, and they concluded that the use of the voice assistant increased the number of tasks performed by these students. No publications were recorded for South America and only 8 studies were carried out between Asia, Africa and Oceania.

Studies evaluating VA applications by people with disabilities use different scientific methods (Figure 4). Our results show that most published studies do not report the methodological approach used (n = 31%). There is a mixture of qualitative and quantitative methods, and the literature reviews add up to 19% of the studies found. As examples of methodological diversity, there is the study by Puviarasi, Ramalingam, and Chinnavan (2013), where the authors conducted a case study where they developed a voice assistant application for people with serious physical disabilities, so they could control a wheelchair and the home environment. In this article, the authors concluded that this application facilitated daily tasks and manual efforts. As an example of using Trials, Gentry et al. (2010) conducted a study investigating the effectiveness of voice assistants as a tool for managing tasks of students with autism from public schools in Virginia. In this study, they concluded that these students, after brief training, improved their performance and satisfaction in daily tasks. We found 6 different methodology approaches, still a small number, and demonstrated the possibility of future research with different approaches, such as action research and surveys.

Another important factor identified in our descriptive analysis was the identification of the main deficiencies or health conditions evaluated in studies with voice assistants (Figure 5). Most articles studied the use of VAs by people with degenerative diseases (such as Parkinson's and Alzheimer's disease), because they are conditions that strongly affect the quality of life and independence of these people (e.g. Ienca et al. 2017; Li et al. 2020). Other deficiencies studied were physical, visual and developmental disability; the latter encompasses Autistic Disorders and Asperger Syndrome. Gentry et al. (2008) analysed in their article the efficacy of voice assistants as cognitive aids for people with severe traumatic brain injury, where they accompanied 23 volunteers during the 8-week period. In this study, they inferred that the people who used this technology increased their satisfaction when performing tasks, as well as their self-esteem. In another study, Smith et al. (2021) studied whether using Amazon Alexa and Google Home voice assistants improves the speech intelligibility of people with developmental disabilities. In this article, they considered an intervention group and a control group, totalling 43 participants who used the equipment for 12 weeks. In the end, they found that the group that used voice assistants improved communication, thereby improving their quality of life.

Our study also identified areas where voice assistants are often used. Figure 6 shows that it is more widely

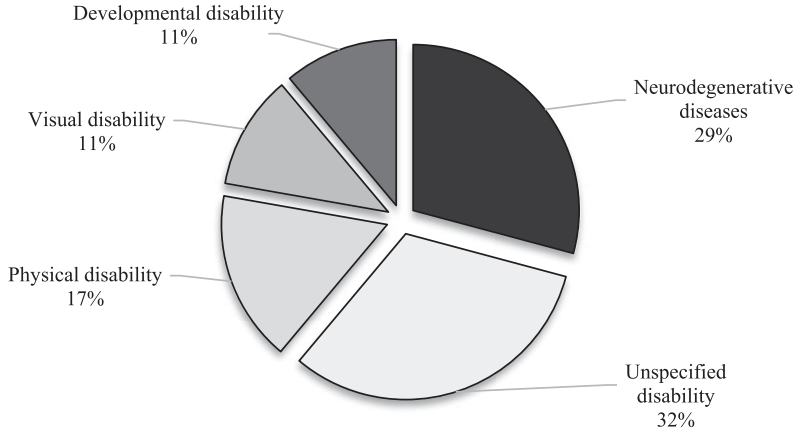

Figure 5. Disability or Health condition.

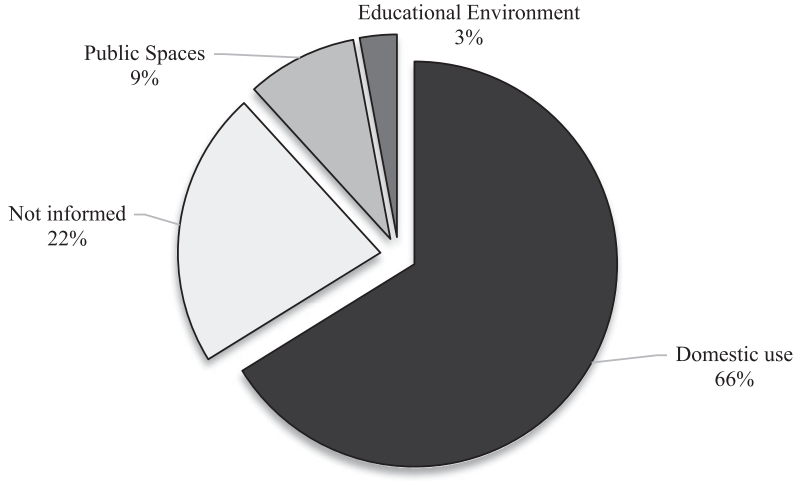

Figure 6. Application area of voice assistants.

used in domestic environments to control smart homes (Aqeel-ur-Rehman and Khursheed 2014), lights (Khalid et al. 2015), and school tasks (Smith Myles, Ferguson, and Hagiwara 2007). A few studies reported their use in public spaces and educational environments. Mechling, Gast, and Seid (2009) described in their study the use of VAs to increase the completion of school tasks by high school students with autistic spectrum disorder and concluded that the use of VAs encouraged students to perform their tasks, supporting their daily activities through observation and interviews with the student and also with their teachers.

4.2. Thematic analysis

Thematic analysis is a common form of presentation of qualitative analysis that identifies relevant themes that arise from the codes found in the articles (Braun and Clarke 2006). Aligned with RQ1 and RQ3, we sought to select the codes that serve as benefits and challenges of the voice assistants. The objective is to remove the codes from the articles, group them according to the frequency of repetition in the literature, and then organise these codes by themes. In this section, we provide descriptions of the emergent codes and evidence of the emergent themes that will be later discussed in the discussion section.

4.2.1. Emergent codes – benefits

One of the objectives of this SLR is to contribute in a prescriptive manner and to understand the main impacts of using voice assistants by people with disabilities (RQ1) and their challenges (RQ3). Thus, Table 1 presents the main benefits of using a VA; these benefits are codes that have been identified as part of the thematic analysis that will be presented below. An important factor we find is that these benefits affect not only the person who uses the VA but also their family and

Table 1. Benefits.

Main benefits – Codes	Sources
Support to daily activities	Hart, Hawkey, and Whyte (2002), Manaris, Macgyvers, and Lagoudakis (2002), Teolis, Dee, and Todd (2004), Baumgart (2005), Gentry et al. (2008), Bharucha et al. (2009), Mechling, Gast, and Seid (2009), Gentry et al. (2010), Mechling and Savidge (2011), Puviarasi, Ramalingam, and Chinnavan (2013), Charters, Gillett, and Simpson (2015), Odokuma and Ndidi (2016), Busatlic et al. (2017), Ienca et al. (2017), Hoy (2018), Nam and Kim (2018), Masina et al. (2020), Ermolina and Tiberius (2021), Sezgin et al. (2021)
Friendly technology	Manaris, Macgyvers, and Lagoudakis (2002), Smith *et al.,* (2007), Lancioni et al. (2009), Khalid et al. (2015), Peeters, Harbers, and Neerincx (2016), Wolters, Kelly, and Kilgour (2016), König et al. (2017), Barata et al. (2018), Morris et al. (2018), Noda (2018), Li et al. (2020), Masina et al. (2020), Milne-Ives et al. (2020), Schachner, Keller, and von Wangenheim (2020), Bérubé et al. (2021), Duffy et al. (2021)
Enhanced level of independence	Chapman and McCartney (2002), Smith *et al.,* (2007), Gentry et al. (2010), Harris (2010), Mechling and Savidge (2011), Charters, Gillett, and Simpson (2015), Khalid et al. (2015), Muñoz et al. (2016), Darcy, Green, and Maxwell (2017), König et al. (2017), Noda (2018), Jamwal et al. (2020), Lancioni *et al.,* (2020), Lancioni *et al.,* (2020), Smith et al. (2020)
Cost-effective technology	Chapman and McCartney (2002), Gentry et al. (2010), Doughty (2011), Puviarasi, Ramalingam, and Chinnavan (2013), Aqeel-ur-Rehman and Khursheed (2014), Kumar and Shimi (2015), Chivarov et al. (2018), Noda (2018), Ayantunde et al. (2019), Lancioni *et al.,* (2020), Leporini, Rosellini, and Forgione (2020), Masina et al. (2020), Schachner, Keller, and von Wangenheim (2020), Smith et al. (2021)
Enhanced quality of life	Chapman and McCartney (2002), Chang, Omery, and Mayo (2003), Baumgart (2005), Aqeel-ur-Rehman and Khursheed (2014), Chivarov et al. (2018), Jamwal et al. (2020), Lancioni *et al.,* (2020), Smith et al. (2020), Smith et al. (2021)
Improved self-esteem	Gentry et al. (2008), Gentry et al. (2010), O'Neill and Gillespie (2008), Charters, Gillett, and Simpson (2015), Peeters, Harbers, and Neerincx (2016), Darcy, Green, and Maxwell (2017)
Increased social participation	Muñoz et al. (2016), Peeters, Harbers, and Neerincx (2016), Darcy, Green, and Maxwell (2017), Jamwal et al. (2020), Smith et al. (2020)
Improved control of the environment	Noyes, Haigh, and Starr (1989), Gentry et al. (2008), Aqeel-ur-Rehman and Khursheed (2014), Kumar and Shimi (2015), Noda (2018)
Improved the communication	Darcy, Green, and Maxwell (2017), Sezgin *et al.,* (2020), Ermolina and Tiberius (2021), Sezgin et al. (2021)
Savings with professional care	Chapman and McCartney (2002), Bharucha et al. (2009), König et al. (2017), Noda (2018)

caregivers (e.g. Darcy, Green, and Maxwell 2017; Sezgin et al. 2021). In addition, we identified for what purpose the VA is mostly used; the results show that users use it to communicate with other devices in the home (e.g. Aqeel-ur-Rehman and Khursheed 2014), request services (e.g. Hoy 2018) and perform tasks (e.g. Mechling, Gast, and Seid 2009). The benefits will be described below and can be found in the table in the order of higher volume of citations.

4.2.1.1. Support to daily activities. Support for daily activities is one of the most cited benefits in studies on using VAs. This support includes, for example, reducing manual effort (e.g. Puviarasi, Ramalingam, and Chinnavan 2013), the improvement in the time of completion and conducting of tasks (e.g. Manaris, Macgyvers, and Lagoudakis 2002; Charters, Gillett, and Simpson 2015), as well as answering various questions that can be asked to VAs (e.g. Hoy 2018). For example, Hoy (2018) concluded that the VA benefits the everyday activities of people with dementia because it is an always-present voice that can answer questions several times patiently, as well as assist in very often-conducted activities. Hart, Hawkey, and Whyte (2002) studied the use of the VA by people with brain injury and found that the device also helped to recall activities and therapy.

4.2.1.2. Friendly technology. Another benefit considered relevant by the literature is that the VA proved to be a friendly technology. Barata et al. (2018) showed in interviews that people described VAs as an 'ease and comfort' technology. Wolters, Kelly, and Kilgour (2016) have developed a voice assistant interface for cognitive assistance for people with dementia in the UK. The authors conducted focal groups to understand the difficulties of use, acceptability and suggestions for improvement in the equipment, and at the end, concluded that the VA helps in complex tasks and was described by the participants as a 'friendly, patient instructor, who adapts their interactive style to the needs of the individual user' (Wolters, Kelly, and Kilgour 2016, 863).

4.2.1.3. Enhanced level of independence. The increase in the level of independence means that people have started to carry out more activities alone (e.g. Smith et al. 2020) and become more independent, both inside and outside the home (e.g. Harris 2010). Lancioni et al. (2022) analysed in their study the access to basic leisure activities, messaging and calls through a voice assistant for people with intellectual and visual disabilities and concluded that the participants were able to carry out these activities independently on their smartphones. Smith Myles, Ferguson, and Hagiwara (2007) studied the use of VAs by American students with Asperger's and concluded that, in addition to being able to carry out a greater number of activities, they also carried them out more independently, with the help of the VA.

4.2.1.4. Cost-effective technology. Compared to other technologies, VAs were also considered a cost-effective technology (Kumar and Shimi 2015; Masina et al. 2020) that appears as a low-cost and affordable solution (Puviarasi, Ramalingam, and Chinnavan 2013). Chapman and McCartney (2002) demonstrated in their study the use of VAs in residential automation applications for people with motor disabilities and reduced mobility and found that in addition to increasing independence, the VA has high potential cost savings with professional care.

4.2.1.5. Enhanced quality of life. The enhanced quality of life represents a more comfortable lifestyle, and it also impacts the families of people with disabilities, who can devote more time to them (Chapman and McCartney 2002; Aqeel-ur-Rehman and Khursheed 2014). For example, Aqeel-ur-Rehman and Khursheed (2014) developed a VA interface to automate the residence of disabled people and people with special needs. The authors concluded that using this device provided a healthier and more comfortable lifestyle and a consequent improvement in the quality of life of people with disabilities.

4.2.1.6. Improved self-esteem. Results related to improved self-esteem showed that there was an improvement in the mood of these people (Peeters, Harbers, and Neerincx 2016), in satisfaction upon completing tasks (Gentry et al. 2010) and in personal satisfaction (Darcy, Green, and Maxwell 2017). Peeters, Harbers, and Neerincx (2016) studied the use of a personal assistant by people with dementia and found that using the equipment encouraged people with dementia to remember old memories, tell life stories, and improve their mood. Gentry et al. (2010) studied the use of VAs by teenagers with autism, and they also noticed that by obtaining support of the equipment to perform their daily activities, they showed greater satisfaction in completing them.

4.2.1.7. Increased social participation. The use of VAs has brought a significant increase in the social participation of individuals with disabilities (Darcy, Green, and Maxwell 2017), as well as the increased contact between the person and their relatives (Peeters, Harbers, and Neerincx 2016). Smith et al. (2020) developed a research to understand the impact of the use of VAs in the well-being of people with intellectual disabilities. In this study, they conducted a trial with an intervention group and a control group, with 44 participants that used the equipment for 12 weeks. The authors concluded that in addition to improving their quality of life, they also allowed greater access to social interactions.

4.2.1.8. Improved control of the environment. The improved control of the environment was stated by people with disabilities through self-evaluation in the improvement of mobility (Gentry et al. 2008) and by facilitating the interaction between the person and the environment (Kumar and Shimi 2015). For example, Noda (2018) studied the use of the Google Home VA as a residential automation device for people with physical disabilities. The use of this device in the study has demonstrated a high capacity to control and manipulate the local environment of the disabled person, such as turning lights on and off, unlocking doors, controlling the air conditioning, opening and closing curtains, and even activating other less conventional appliances, such as a robotic vacuum cleaner or the irrigation system in the garden.

4.2.1.9. Improved the communication. The improvement in communication when using VAs includes the communication of health events (Sezgin et al. 2021), communication with relatives and friends (Darcy, Green, and Maxwell 2017), in addition to the VA being itself a communication tool for both the patient and the health team (Ermolina and Tiberius 2021). Sezgin et al. (2021) developed a VA interface to monitor the care in a home for children with complex and severe diseases, and noted that when using the devices, they remembered to record when any changes in health occurred. Also Darcy, Green, and Maxwell (2017) mentioned in his article that disabled people, using TAs, such as VAs, could access communication applications more easily, and started to interact more with their family and friends.

4.2.1.10. Savings with professional care. Finally, another benefit was the savings with professional care. Several researchers agree in their studies that the use of the VA reduces the burden and need for professional caregivers (cf. Bharucha et al. 2009; König et al. 2017). For example, Noda (2018) who studied the use of Google Home to automate the residence of people with physical disabilities, concluded that by promoting greater control of the environment, the need for caregivers is reduced, promoting savings with professional care.

4.2.2 Emergent Codes – Challenges

Despite all these benefits of using a VA, some challenges were also identified in its applications (Table 2). It is important to understand these challenges so that we can evolve the technology of VAs as an AT of support

Table 2. Challenges.

Main challenges – Codes	Sources
VA difficulties to understand user	Noyes, Haigh, and Starr (1989), Teolis, Dee, and Todd (2004), Gentry et al. (2008), Harris (2010), Doughty (2011), Aqeel-ur-Rehman and Khursheed (2014), Rudzicz et al. (2015), Peeters, Harbers, and Neerincx (2016), Wolters, Kelly, and Kilgour (2016), Darcy, Green, and Maxwell (2017), Noda (2018), Masina et al. (2020), Milne-Ives et al. (2020), Smith et al. (2020), Sezgin et al. (2021)
Concern about security and privacy	Noyes, Haigh, and Starr (1989), Chang, Omery, and Mayo (2003), Baumgart (2005), O'Neill and Gillespie (2008), Bharucha et al. (2009), Doughty (2011), Muñoz et al. (2016), Ienca et al. (2018), Jamwal et al. (2020), Sezgin et al. (2021), Li et al. (2020), Duffy et al. (2021); Ermolina and Tiberius (2021), Sezgin et al. (2021), Smith et al. (2021)
Technical issues	Chang, Omery, and Mayo (2003), Teolis, Dee, and Todd (2004), Bharucha et al. (2009), Doughty (2011), Rudzicz et al. (2015), Ienca et al. (2017), Schachner, Keller, and von Wangenheim (2020), Bérubé et al. (2021)
High cost device	Chang, Omery, and Mayo (2003), Teolis, Dee, and Todd (2004), Baumgart (2005), Harris (2010), Cook and Polgar (2015)
Difficulty in accepting new technologies	Odokuma and Ndidi (2016), König et al. (2017)
Concern on increasing social isolation	Chapman and McCartney (2002), Morris et al. (2018)

for people with disabilities, as well as develop means to overcome these barriers. The challenges described below can be found in the table in the order of higher volume of citations.

4.2.2.1. VA difficulties to understand users. The main difficulty is related to the interaction between the VA and the user, because there is often no understanding by the VA of the given command. This can be related to several factors, such as the presence of other sounds in the environment (Noyes, Haigh, and Starr 1989), people with accents or speech difficulties (Noda 2018), and the need to speak louder (Masina et al. 2020). For example, Harris (2010) observed in his study that a generalised problem area was the excess of voice recognition errors when communicating with the user.

4.2.2.2. Concern about security and privacy. The remote transmission of data is a factor of concern for people with privacy and security of their information (Chang, Omery, and Mayo 2003). Smith et al. (2021) studied the use of the VAs Amazon Alexa and Google Home by people with intellectual disabilities, and stressed in their article that there is great concern about data security, as in all technologies that connect to the Internet. Also Duffy et al. (2021), who explored the use of VAs by people with Parkinson's, found in their study that people were mainly concerned regarding security and privacy with being hacked, the misuse of their personal data, and being spied on and monitored, due to the VA being permanently active, listening to the environment.

4.2.2.3. Technical issues. Some technical problems – of hardware and software – have been reported about the use of VAs, such as slowness (Bérubé et al. 2021), limited number of applications for some models (Schachner, Keller, and von Wangenheim 2020), improvement in computational models of human activity and behaviour (Bharucha et al. 2009), and also the implementation of backup in case of loss (Doughty 2011). Bérubé et al. (2021) carried out a literature review on the use of VAs by people with mental illnesses, and verified that these devices presented a rather slow response to the user.

4.2.2.4. High cost device. The high cost that it represents for a part of the population was a factor mentioned as a challenge for the use of the VA. In a series of interviews conducted by Teolis, Dee, and Todd (2004), 20% of the participants placed the high cost as a hindrance in the use of this technology. Chang, Omery, and Mayo (2003) studied the use of VAs by teenagers with severe diseases, and concluded that among the challenges of implementing this technology, was the need to justify the cost-benefit ratio, due to being a high-value equipment.

4.2.2.5. Difficulty in accepting new technologies. Two studies have demonstrated the difficulty in accepting new technologies as a challenge. Odokuma and Ndidi (2016) demonstrated in their study that people are still sceptic regarding the use of more modern technologies, such as VAs. König et al. (2017) mention that despite the scepticism, to overcome this barrier developers of this technology should include the users' and stakeholders' vision in the development and manufacture of new products.

4.2.2.6. Concern on increasing social isolation. Finally, in addition to the challenges already mentioned, there was concern about the use of VAs resulting in an increase in social isolation. Morris et al. (2018), who carried out in their article the analysis of an empathetic VA for the use of people with mental disabilities, state and raise the question in their article that if over time, people seek emotional support from machines, rather than their relatives, and that it is necessary to investigate

how to maintain 'human-human' relationships using the benefits provided by the technology. Chapman and McCartney (2002), who studied the VA as a residential automation device for people with motor disabilities, also pointed out that attention is needed to ensure that the use of this technology does not result in social isolation.

Finally, as a descriptive result of our study, we have selected ten studies that provide a detailed research protocol for VA applications on people with disabilities (Table 3). For instance, how VA was applied, in which population, for how long, and the device used. Our results show that most of the studies have used comparison methodologies of before and after VA usage. Users had a short induction section and independently used the device for a given study period (e.g. Hart, Hawkey, and Whyte 2002; Gentry et al. 2008; Mechling and Savidge 2011; Smith et al. 2021).

The device's efficiency was tested by Hart, Hawkey, and Whyte (2002) who conducted a study with 10 participants with severe brain injury. After a short adaptation period, the participants used the device for 32 weeks, during which the researchers followed the interactions between users and the device. They have found that VA technology has a vast potential to support activities that rely on memory. Other studies using laboratory observations, training and use, and interventional studies with different populations are displayed in Table 3 (e.g. Mechling, Gast, and Seid 2009; Leporini, Rosellini, and Forgione 2020; Masina et al. 2020). These studies in Table 3 present a response to our RQ4 and summarise research protocols and approaches found in the VA literature.

4.2.3 Emergent Themes

In this stage, we present the results of the thematic analysis that identified emergent themes representing the benefits and challenges of using the VA by people with disabilities. The definition of these themes is characterised by finding and categorising important research-related themes, analysed through a set of codes (e.g. Braun and Clarke 2006). For example, for the benefits, we grouped and codified similar benefits, which resulted in 4 themes. We performed the same procedure for the challenges, which resulted in 3 themes. Appendices B and C present a detailed analysis of these themes, the number of times that they appeared in the literature, the codes that were categorised to give rise to the themes, as well as evidence in the literature that confirmed these themes. Because these are themes that emerged from the literature and had an impact on the contribution of our study, we present the thematic analysis of the issues of challenges and benefits in this section, but we discussed in depth each theme in light of the literature and its contribution to theory and practice in the next section.

5. Discussion

In this section, we provide an in-depth discussion of the themes that emerged from our results (appendices B and C), and together with the literature, we discuss the main contributions to theory and practice. The themes will address the benefits and challenges of the VA's impact on people with disabilities considering a tripartite division of micro, meso and macro-level phenomena, which answers our RQ1 and RQ3.

5.1. Contributions to people with disabilities' ecosystem and well-being

Bringing the discussions closer to the heart of our research purpose, which is to understand the impact of VAs on people with disabilities, we found contributions that go beyond descriptive findings on individuals but underscore the impact on society and organisations alike. Therefore, we provide a multilevel framework that connects our contributions to the actors' ecosystem and well-being at the micro, meso and macro-level (Figure 7). By definition in our study, we consider the micro-level as the individuals and their families, which include people with disability or health conditions. At the meso-level, we have organised groups and citizenry; this is the level at which we find charities, non-profit organisations and other individuals (including groups) who are affected by technological changes in the ecosystem. Finally, the macro-level congregates key stakeholders, private and public organisations, policy-makers, and technology design and evaluation. To some extent, these levels naturally overlap (see the arrows between the levels), and in different degrees, they might touch on all levels. This interrelating process is observed by Liljenstrom and Svedin (2005) who describe the meso-level as a domain where the bottom-up level meets the top-down level. Because the aim of our study is not to measure times of inferences in the levels but to understand the impact of technology in the wider ecosystem, we decided to prioritise the two main contributions that each theme makes to a level.

5.1.1. Technology impact on users' ecosystem (micro and macro-levels)

For people with a disability or health condition, daily life can be challenging and full of restrictions imposed by the environment. In that sense, the emerging VA

Table 3. VA's use approaches in the literature.

Voice Assistant	Purpose	Population	Protocol	Length	Size Groups / Participants	Main Results	Source
Not specified VA	The purpose of this study was to evaluate the use of a Personal Digital Assistant with multiple prompt levels to increase completion of novel task boxes and transitioning within and between tasks	Adolescents with Autism spectrum	Pre and Post interventional study	4 weeks	3 participants	Results indicated that task completion was higher compared to baseline conditions and the students were able to complete a greater number of between task transitions using the PDA	Mechling *et al.,* (2011)
Not specified VA	The purpose of this study was to examine the efficacy of personal digital assistants (PDAs) as cognitive aids in a sample of individuals with severe traumatic brain injury	Adults with brain injury	Pre and Post interventional study	8 weeks	23 participants	A brief training intervention utilising PDAs as cognitive aids is associated with improved self-ratings of performance in everyday life tasks	Gentry et al. (2008)
Not specified VA	This paper introduces a audio-based tool aimed at supporting visually-impaired people in the seemingly simple activity of checking whether the light in a room is on or off	Blind Adults and Elderlies	Comparison between the use of blind and sighted users	Not informed	12 participants	This study gives a contribution in the ambient intelligence field by showing how an auditory-based tool can be used to support totally blind people to check the lights in an autonomous and relatively simple way	Leporini, Rosellini, and Forgione (2020)
Google Assistant	Investigate the use of Google Assistant to help participants with intellectual and visual disabilities manage leisure engagement and communication with distant partners in an independent manner	Adults with intellectual and visual disabilities	Pre and Post interventional study	About 10 weeks	6 participants	During the post-intervention phase, all participants accessed leisure events and made telephone calls or sent and received messages independently	Lancioni *et al.,* (2020)
Not specified VA	The purpose of this study was to examine the efficacy of personal digital assistants (PDAs) as task management tools in a sample of transition-age high school students with autism	Adolescents with Autism spectrum	Pre and Post interventional study	8 weeks	22 participants	A brief training intervention utilising PDAs as cognitive aids is associated with improved self-ratings of performance and satisfaction in everyday life tasks among a group of high school students with autism	Gentry et al. (2010)
Not specified VA	Determine whether the use of a personal digital assistant (PDA) would facilitate the recording of homework by an adolescent boy with Asperger	Adolescents with Asperger Syndrome	Pre and Post interventional study	About 4 weeks	1 participant	The student was successful in increasing his rate of home-work recording by using a PDA	Smith Myles, Ferguson, and Hagiwara (2007)
Not informed	In this study, a personal digital assistant (PDA) with picture, auditory, and video prompts with voice over, was evaluated as a portable self-prompting device for students with autism spectrum disorder	Adolescents with Autism spectrum	Multiple probe design	Not informed	3 participants	Results indicate that the students with ASD were able to adjust the prompt levels used on the PDA and to maintain their ability to use the device to independently complete recipes over time	Mechling, Gast, and Seid (2009)
Google Home	The aim of this work is to investigate whether cognitive and/or linguistic functions could predict user performance in operating an off-the-shelf voice assistant	Adults with motor disabilities	Study in a living laboratory	Not informed	16 participants	Users with motor, linguistic, and cognitive impairments can effectively interact with voice assistants, given specific levels of residual cognitive and linguistic skills	Masina et al. (2020)
Amazon Alexa and Google Home	To determine whether providing individuals with intellectual disabilities with smart speaker devices improved ratings of speech intelligibility	Adults with intellectual disability	Pre and Post interventional study	12 weeks	43 participants	The group that received smart speakers made significantly larger intelligibility gains than the control group	Smith et al. (2021)
Not informed	To test the efficacy of a portable voice organizer in helping people with traumatic brain injury to recall therapy goals and plans discussed with their clinical case managers	Adults with brain injury	Training and use	32 weeks	10 participants	Portable electronic devices have the potential to assist with treatment areas beyond tasks involving prospective memory	Hart, Hawkey, and Whyte (2002)

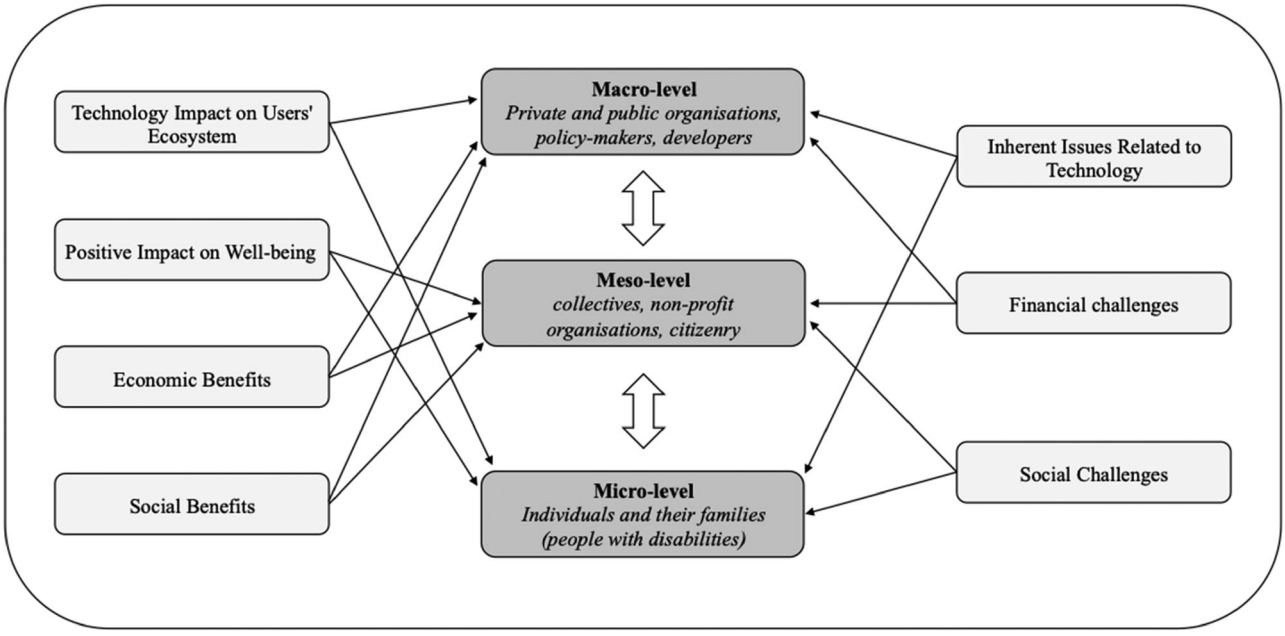

Figure 7. Impact on people with disabilities' ecosystem and well-being.

technology is already having an impact on the users' ecosystem by providing accessibility, mobility, and supporting daily activities (Manaris, Macgyvers, and Lagoudakis 2002; Barata et al. 2018; Gentry et al. 2008). In this micro-level example, we also observe the impact on those around the user, enabling the family member to provide less assistance (e.g. Chapman and McCartney 2002). On the other hand, at the macro-level the use of AT technology also impacts the wider ecosystem, for instance, prompting legislation development to make VAs more accessible to people with disabilities, which might positively impact this population's independence and reduce the burden on social services.

5.1.2. Positive Impact on Well-being (micro and meso-level)

One of the main aims of any new technology-oriented to assist people with disabilities is to enhance users' well-being. We have found that the VA technology has had a positive impact on the micro-level of users by enhancing their well-being, independence, quality of life, and self-esteem (e.g. Chapman and McCartney 2002; Harris 2010; Darcy, Green, and Maxwell 2017). As autonomy is one of the main obstacles for people with disabilities, ATs can provide support to overcome this difficulty and include these populations in their communities, and enhance social interactions (König et al. 2017). In this meso-level, we identify users with physical mobility affected, who are still able to interact orally, taking advantage of VA technology for well-being enhancement and social inclusion (e.g. social media participation, online events, inclusion in interest groups, and having access to information).

5.1.3. Economic benefits (meso and macro-levels)

The financial benefit of the VA technology is twofold. First, VA device prices have become considerably accessible to the population in general, possibly because VAs have become a standard technology, both in devices that are already built-in within users' smartphones (e.g. Siri) or physical devices, like Google Home and Alexa (Masina et al. 2020). Second is the labour cost reduction associated with using VA technology (Bharucha et al. 2009), as people with severe disability or health conditions require a caregiver, a family member, or a third party to provide support. Hence, our findings underline technology accessibility and cost reduction as part of the meso-level because they have a positive impact on resource-limited environments, such as non-profit organisations that can afford to rely on this VA technology to reduce staff burden and encourage interaction with wider users (e.g. Harniss, Samant Raja, and Matter 2015; Smith et al. 2021). As the VA technology becomes popular, it touches on the macro-level and impacts areas of public management. More specifically, social services are able to use this AT to enhance the coverage and capacity of services, as well as communicate with those who need support. This approach to technology bridges the gap between access and innovation in public services and benefits the citizenry.

5.1.4. Social benefits (meso and macro-levels)

The understanding of these benefits is aligned with our research aim and goes beyond the benefits for disabled individuals but shows the impact on the society in which these individuals are inserted (meso-level). Our results show that VA technology has improved the communication and interactions between its users and other social actors (Darcy, Green, and Maxwell 2017). The use of VA also increased social interactions and provided wider inclusion of people with disabilities in society (including the digital world) (e.g. Gentry et al. 2008; Peeters, Harbers, and Neerincx 2016). At the macro-level, the social benefits of the VA technology are virtually touching on key stakeholders, from people with disabilities and developers' perspectives, enabling them to rethink products and how they are offered to special populations. This is an emerging necessity and raises legislators' awareness to develop more inclusive regulations to support the wider implementation of AT in both public services and venues (e.g. Borg, Larsson, and Östergren 2011).

5.1.5. Inherent issues related to technology (macro and micro-level)

Challenges related to hardware and software are still a problem to be addressed with the research and development (R&D) of the product and technology. The literature raises problems related to the slow response of the device, internet connection, limited software and applications, as well as lack of focus on people with a disability or health condition (e.g. Chang, Omery, and Mayo 2003; Ienca et al. 2017; Schachner, Keller, and von Wangenheim 2020). These technological issues involve macro-level stakeholders, such as designers, developers and organisations that brand and sell VA devices. We believe that studies similar to ours and others using empirical data can help to improve the technology based on users' perceptions (e.g. Morris et al. 2018; McLean and Osei-Frimpong 2019). Our findings also raise users' concerns with data security and privacy, as this type of technology might 'open' the doors of their houses to outsiders (e.g. Ienca et al. 2017; Ermolina and Tiberius 2021). This is an issue to be addressed not only by companies but also policymakers, who must create user-oriented legislations that protect the data and privacy of users. Finally, at the micro-level but overlapping with stakeholders at the macro-level, users have reported difficulties while interacting with the technology. Some of the technical issues are related to the lack of the device's understanding and precision, the need to speak louder, interference of background noises and voice recognition difficulties (e.g. Milne-Ives et al. 2020; Bérubé et al. 2021; Sezgin et al. 2021).

5.1.6. Financial challenges (macro and meso)

Although in the benefits we have discussed that the cost of VA technology is becoming more affordable, we also found that cost is still considered unaffordable for some stakeholders at the meso-level, such as citizenry and organised groups who aim to fully adopt the technology (e.g. Teolis, Dee, and Todd 2004; Cook and Polgar 2015). The continued popularisation of the technology might help to ease this challenge, but at the macro-level companies must continue to invest in R&D to reduce production costs; and product subsidies from public administration might democratise the access of people with disabilities to VA technology (Ely, Van Zwanenberg, and Stirling 2014).

5.1.7. Social Challenges (meso and micro)

This theme addresses the 'dark-side' of technology. We discuss how VA technology can increase social isolation, in which users have immersed themselves into the technology to the point that they prefer to interact with the VA instead of family and friends (e.g. Chapman and McCartney 2002; Morris et al. 2018). At the meso-level, we believe that organised groups and other organisations that work with these people with disabilities play a fundamental role in mediating the use of technology blended with human interactions and engagement (e.g. event creations and groups of interest). Finally, at the micro-level, a study conducted by Odokuma and Ndidi (2016) with elderly and disabled people found a degree of scepticism from some users in relation to the VA technology. This indicates that technology is not a 'one size fits all' strategy, and individuals will independently accept or not the VA technology into their lives.

This section addressed the impact of VA technologies on individuals with disabilities and their families, society and organisations. Although the results make significant contributions, we highlight some divergences between themes, which shows the importance of avoiding generalisations. This technology cannot be taken as a 'one size fits all' strategy (mainly when applied to vulnerable groups). For instance, several studies suggest that the VA technology is user-friendly (e.g. Duffy et al. 2021); conversely, some studies identified a degree of scepticism from users and even difficulties with VA interaction as a barrier (e.g. Odokuma and Ndidi 2016). Another example is the benefit of cost-effective technology and the challenge of the high-cost device; however, in this case, two elements might contribute to this issue; first, people have different socio-economic backgrounds, and the perceptions of expensive or affordable may vary between people; second, the studies that found this high-cost issue are dated from when the technology was emerging and therefore, more expensive.

In a nutshell, the VA technology's benefits and challenges presented in this section virtually touch on every element of the people with disabilities ecosystem (macro, meso and micro-levels). Therefore, this provides an understanding of the VA technology's impact on people's well-being, and this might shorten the gap between excluded individuals and their re-inclusion in society.

5.2. Research agenda

In this section, we address the VA technology's perspective and research calls in the field, which helps to answer our RQ4. Drawn from our findings in the literature, we outline a research agenda with research questions that is expected to motivate other scholars to address timely issues found in the literature (Table 4).

Our results show seven trending themes as research calls in the literature. As an informative purpose, we will provide all themes in Table 4, but we will only discuss the top three most cited topics that emerged in our analysis, as they represent 71% of the research agenda. The first theme is focused on the performance of the VA device; this topic echoes some technological challenges found in our previous discussion (Manaris, Macgyvers, and Lagoudakis 2002; Duffy et al. 2021). Empirical studies, such as trials with different populations might shed light upon this issue and help companies and developers to improve the technology. Our research questions focused on long-term studies involving the users (co-design) to identify elements needing improvement.

In a similar vein, the second theme addresses the need for a larger and more inclusive sample in the studies, as well as observations in longitudinal studies (Peeters, Harbers, and Neerincx 2016; Masina et al. 2020). The research questions that orient this theme focus on VA's long-term impact on different populations, for instance, the elderly and developing countries. The third theme explores VA usage's social impact and contributions (Lancioni et al. 2022; Apergi et al. 2021). In this theme, our research questions aim to shed light upon critical social care issues and the social inclusion of disabled populations. The remaining themes are equally important, and the literature and research questions presented in table 4 might help scholars and managers to develop these topics further.

5.3. Contribution to theory

In our study we identified several contributions to theory, these contributions have been previously displayed throughout the article, but we have summarised them in this section. Firstly, we addressed the void in the literature and provided answers to the dearth of studies unifying the impact of VA technology on the lives of people with disabilities (e.g. Carver et al. 2016; Labonnote and Høyland 2017; Hoy 2018). Secondly, by addressing this research problem, we answer timely research calls (e.g. Chang, Omery, and Mayo 2003; Anderson, Nasr, and Rayburn 2018; Masina et al. 2020; Ostrom et al. 2021; Smith et al. 2021) and categorise the literature, providing a descriptive overview of the VA studies and an in-depth thematic analysis that discusses the technology impact on the people with disabilities ecosystem and well-being in different levels (micro, meso and macro-levels). Thirdly, we confirm previous results that show the benefits and barriers faced by people with a disability or health condition while accessing ATs (e.g. Wolters, Kelly, and Kilgour 2016; Lancioni et al. 2022; Schachner, Keller, and von Wangenheim 2020; Duffy et al. 2021). Finally, we provide a research agenda with timely research questions that scholars and managers can address in future studies.

5.4. Contribution to practice

Our study underlines several contributions to practice that cover micro, meso and macro-levels. For instance, results have shown a variety of issues involving the VA technology and users, such as data privacy and security and lower accessibility. We contribute to practice by urging policy-makers to develop more inclusive and protective legislations that enable the wider implementation of ATs. Concurrently, as cities move towards the concept of 'smart cities', technology becomes a current theme. Hence, we raise the awareness of legislators to discuss new regulations and laws that thwart and prevent unauthorised access to user data and privacy. For organisations that sell these VA devices under different brands, but with the same purpose of creating wider interactions, we underscore several challenges that need to be addressed for technology to be popularised amongst people with disabilities. In that sense, we provide several research topics that might help to ease the challenges faced by users.

6. Concluding remarks

The most germane contribution of our study is to provide the answer to our research questions and aims, which is to understand the impact of VA technology on the ecosystem of people with disabilities (RQ1 and RQ3), to outline the VA literature for people with disabilities (RQ2) as well as to identify protocols and perspectives for this emerging technology (RQ4). The

Table 4. Research calls.

Research Calls	%	Research Questions	Sources
Studies focused on improvements of the VA performance.	38%	• How can developers, factories and users work together to co-design VA devices? • What is the impact of long-term VA use on AI improvement? • What are the VA key performance elements need improvements from the users' perspective?	Manaris, Macgyvers, and Lagoudakis (2002), Doughty (2011), Puviarasi, Ramalingam, and Chinnavan (2013), Aqeel-ur-Rehman and Khursheed (2014), Charters, Gillett, and Simpson (2015), Khalid et al. (2015), Rudzicz et al. (2015), Wolters, Kelly, and Kilgour (2016), Busatlic et al. (2017), Chivarov et al. (2018), Hoy (2018), Nam and Kim (2018), Lancioni *et al.,* (2020), Leporini, Rosellini, and Forgione (2020), Li et al. (2020), Smith et al. (2020), Schachner, Keller, and von Wangenheim (2020), Bérubé et al. (2021), Duffy et al. (2021)
Studies with a larger and more inclusive sample, during a longer period of time	23%	• To what extent does the long-term use of VA impact people with disabilities? • How can VA support ageing groups' needs? • Is the use of VA in other non-English speakers countries effective?	Chang, Omery, and Mayo (2003), Smith *et al.,* (2007), Gentry et al. (2008), Peeters, Harbers, and Neerincx (2016), Ienca et al. (2017), Morris et al. (2018), Kettlewell, das Nair, and Radford (2019), Lancioni *et al.,* (2020), Masina et al. (2020), Smith et al. (2020), Sezgin et al. (2021)
Explore social aspects and applications of VA usage	10%	• To what extent does the VA adoption impact social care? • How does the use of VA technologies support social inclusion? • To what extent do VA technologies promote social inclusion for disabled people?	Noyes, Haigh, and Starr (1989), O'Neill and Gillespie (2008), Lancioni et al. (2009), König et al. (2017), Lancioni *et al.,* (2020), Apergi et al. (2021)
Studies focusing on user needs and preferences to develop better devices	9%	• How can visual recognition be implemented and used in future VA devices? • What are the main value propositions that users identify on VAs? • How can co-designing help organisations to provide VA technologies that meet the users' needs?	Hart, Hawkey, and Whyte (2002), Bharucha et al. (2009), Mechling, Gast, and Seid (2009), Doughty (2011), Sezgin et al. (2021)
Research addressing privacy and security problems	6%	• What privacy trade-offs are users willing to accept in exchange for better services? • How can policy-makers, users and organisations work together to develop policies for transparency in data protection? • How can organisations develop more transparent policies for access to users' environment?	Doughty (2011), Li et al. (2020), Milne-Ives et al. (2020)
Adoption of VA by people with severe disabilities	6%	• To what extent can VA be adapted for people with severe impairments? • How can neural-interface-technology be used to advance VA use for severe disabilities? • To what extent might VA technologies support degenerative brain diseases?	Ienca et al. (2018), Nam and Kim (2018), Smith et al. (2020)
Applications of VA in different environments	4%	• What are the implications of VA in supporting students in schools? • To what extent could other AI technologies, such as ChatGPT, be applied to VA to benefit schools and universities? • What is the impact of VA use in hospital wards?	Gentry et al. (2010), Ayantunde et al. (2019)
Investigation of the VA cost-benefit	4%	• What is the long-term economical impact of VA? • To what extent can VA technologies replace social care support based on the workforce? • How beneficial is the implementation of VA technologies in care homes?	Khalid et al. (2015), Milne-Ives et al. (2020)

first part of our SLR presents an overview of the literature with the distribution of the publications per year and region, main journals, methodologies applied, types of disability or health condition, and areas of VA applications, which together congregate the descriptive results. By travelling back and forth in the literature, we conducted a thematic analysis and found codes and meaningful themes that together help to understand the benefits and challenges of VA applications.

Finally, the study has its limitations. Although we have carried out an SLR based on strict procedures, it is possible that a few articles may not have been retrieved during our searches. As searches were performed only in English, it is possible also that relevant articles that are not in English were not considered in this study. To ease the impact of this limitation, we have applied a rigorous PRISMA protocol and research guidelines for SLR based on Tranfield, Denyer, and Smart (2003) and Moher et al. (2009). Another limitation is that the conducted thematic analysis may possess subjective characteristics, meaning it is subject to the researcher's judgment and interpretations. To

minimise this limitation, we formed a review panel to audit the thematic analysis. Additionally, an external member (an academic expert in thematic analysis) also audited the codes and themes, cross-referenced, and helped validate the findings. Our research protocol does not address VA applications in the workplace; acknowledging that people with disabilities can hold a job for their livelihood, we suggest future studies address this limitation of our study, providing an SLR that includes the workplace (i.e. keyword). Finally, we have made several suggestions for future research in Table 4, and we trust that the outcomes from this study motivate further empirical studies.

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Appendix A. Journals

#	Journals	N°	%
1	Journal of Medical Internet Research	8	12%
2	Disability and Rehabilitation: Assistive Technology	6	9%
3	Assistive Technology	2	3%
4	International Journal of Engineering Applied Sciences and Technology	2	3%
5	Journal of Assistive Technologies	2	3%
6	Journal of Autism and Developmental Disorders	2	3%
7	AACN clinical issues	1	1%
8	ACM Transactions on Accessible Computing	1	1%
9	American Journal of Geriatric Psychiatry	1	1%
10	Applied Ergonomics	1	1%
11	Assistive Technologies, Principles and Practice	1	1%
12	BMC Geriatrics	1	1%
13	Brain Injury	1	1%
14	Clinical Rehabilitation	1	1%
15	Computers in Human Behavior	1	1%
16	Disability and Society	1	1%
17	Expert Systems with Applications	1	1%
18	Focus on Autism and other developmental disabilities	1	1%
19	Health Informatics Journal	1	1%
20	IEEE Transactions on Cognitive and Developmental Systems	1	1%
21	IFAC	1	1%
22	International Journal of Advanced Research in Electronics and Communication Engineering	1	1%
23	International Journal of Advances in Engineering Research	1	1%
24	International Journal of Developmental Disabilities	1	1%
25	International Journal of Language and Communication Disorders	1	1%
26	International Journal of Modern Engineering Research	1	1%
27	International Journal of Social Robotics	1	1%
28	International Journal of Speech Technology	1	1%
29	International Research Journal of Computer Science	1	1%
30	Irish Journal of Psychology	1	1%
31	JMIR Formative Research	1	1%
32	JMIR mHealth and uHealth	1	1%
33	JMIR Rehabilitation and Assistive Technologies	1	1%
34	Journal Applied Environmental and Biological Sciences	1	1%
35	Journal of Alzheimer's Disease	1	1%
36	Journal of Ambient Intelligence and Humanized Computing	1	1%
37	Journal of Electronic Resources in Medical Libraries	1	1%
38	Journal of Head Trauma Rehabilitation	1	1%
39	Journal of Rehabilitation and Assistive Technologies Engineering	1	1%
40	Journal of the American Dietetic Association	1	1%
41	Journal of Vocational Rehabilitation	1	1%
42	Library Hi Tech News	1	1%
43	Medical Reference Services Quarterly	1	1%
44	Neuropsychological Rehabilitation	1	1%
45	Property Management	1	1%
46	Research in Developmental Disabilities	1	1%
47	Science and Engineering Ethics	1	1%
48	Survey of Ophthalmology	1	1%
49	Technological Forecasting and Social Change	1	1%
50	TEM Journal	1	1%
51	The Lancet	1	1%
52	Transportation Research Procedia	1	1%

Appendix B. Themes from Benefits

Themes	% of times mentioned in the literature	Codes	Representative quotes from the literature
Technology Impact on Users' Ecosystem	41%	Friendly technology	*The suggested design metaphor is a friendly, patient instructor, who adapts their interaction style to the needs of the individual user. (Wolters, Kelly, and Kilgour 2016, 863)*
		Improved control of the environment	

(*Continued*)

Continued.

Themes	% of times mentioned in the literature	Codes	Representative quotes from the literature
			The use of an ECU has been shown to significantly improve the person's independence and quality of life by its ability to control or manipulate the local environment. (Noda 2018, 2)
		Support to daily activities	*A brief training intervention utilising PDAs as cognitive aids is associated with improved self-ratings of performance in everyday life tasks among community-dwelling individuals with severe TBI. (Gentry et al. 2008, 19)*
Positive Impact on Well-being	32%	Enhanced level of independence	*During the intervention and post-intervention phases (with the support of the voice recording devices), all participants managed to access the types of stimulation available independently. (Lancioni et al. 2022, 1)*
		Enhanced quality of life	*While the mechanism of action remains to be determined, the presence of smart speakers in the home had a demonstrable impact on ratings of speech intelligibility, and could provide cost-effective inclusive support for speech and communication improvement, improving the quality of life of vulnerable populations. (Smith et al. 2021, 583)*
		Improved self-esteem	*Among the 23 participants, this study demonstrates significantly improved self-estimation of occupational performance in everyday life tasks and in satisfaction with performance, while also demonstrating significantly improved self-ratings for level of participation in the areas of cognition, mobility and occupation. (Gentry et al. 2008, 23)*
Economic benefits	18%	Cost-effective technology	*However, even if the smart speaker's influence on improvement is partly indirect, it is still a relatively simple and cost-effective solution. (Smith et al. 2021, 591)*
		Savings with professional care	*Service providers are interested in the financial savings which might arise from the reduction in need for care assistants to help with manual tasks. (Chapman and McCartney 2002, 165)*
Social benefits	9%	Improved the communication	*In particular many of the participants developed greater independence in their local communities which was evident in an increased independent use of public transport, increased communication with relatives and friends, use of the Help Centre (environmental factors) and the development of new skills and activities such as taking photos, storytelling and sharing these with family and friends (human factors). (Darcy, Green, and Maxwell 2017, 9)*
		Increased social participation	*The findings indicate that for the majority of users, the mobile technology increased the participants communication and social participation. (Darcy, Green, and Maxwell 2017, 1)*

Appendix C. Themes from Challenges

Themes	% of times mentioned in the literature	Codes	Representative quotes from the literature
Inherent Issues Related to Technology	82%	VA difficulties to understand user	*While working on the system, several limitations are highlighted, such as the system produces error in response to environmental noise, and requires absolute silence and solitude to work properly, otherwise it can pick noise signals, and produce error in response to it. (Aqeel-ur-Rehman and Khursheed 2014, 63)*
		Concern about security and privacy	*Privacy and confidentiality concerns with VAT are a current topic of significant discussion within the media and academia. The results from our survey indicate that the majority of respondents were not seriously concerned about privacy and confidentiality. However, more than one-third of respondents did have slight concerns, and 9.3% were very concerned. Specific concerns were around the potential for hacking, misuse of personal data, and surveillance potential. (Duffy et al. 2021, 10)*
		Technical issues	*So far, this evolving field of research has a limited number of applications tailored for chronic conditions, despite their medical prevalence and economic burden to the health care systems of the twenty-first century. (Schachner, Keller, and von Wangenheim 2020, 12)*
Financial challenges	10%	High cost device	*However, there are many challenges to continued productive engagement with advanced technologies for disabled people. Not least of these are the financial costs, which can prove a formidable barrier for many disabled people. (Harris 2010, 436)*
Social Challenges	8%	Difficulty in accepting new technologies	*In a country like Nigeria where many individuals are skeptical to new technology, systems like speech recognition, speech synthesis, robotics etc. (Odokuma and Ndidi 2016, 66)*
		Concern on increasing social isolation	*Attention must be given to ensuring that this technological support does not result in increased social isolation. (Chapman and McCartney 2002, 165)*