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EDITED BY
Waganesh A. Zeleke,
Duquesne University, United States

REVIEWED BY
Janika Leoste,
Tallinn University, Estonia
Elena Smolianina,
National Research University Higher School of Economics (Perm), Russia

*CORRESPONDENCE
Alejandro Valencia-Arias
✉ valenciajho@crece.uss.edu.pe

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Benefits and development of assistive technologies for Deaf people's communication: A systematic review

Paula Andrea Rodríguez-Correa[1,2], Alejandro Valencia-Arias[2,3]*, Orfa Nidia Patiño-Toro[2], Yober Oblitas Díaz[3] and Renata Teodori De la Puente[4]

[1]Centro de investigaciones, Institución Universitaria Escolme, Medellín, Colombia, [2]Departamento de Ciencias Administrativas, Instituto Tecnológico Metropolitano, Medellín, Colombia, [3]Facultad de Ingeniería, Arquitectura y Urbanismo, Universidad Señor de Sipán, Chiclayo, Peru, [4]Universidad de San Martín de Porres, Lima, Peru

The development of technologies has made digital accessibility relevant to many everyday processes. Multiple resources have been designed to meet the special needs of a wide variety of people, such as Deaf sign language users, who require inclusive technologies to facilitate their communication in work, educational, and social environments. The objective of this study is to identify assistive technologies that favor and improve communication between Deaf and hearing people. To this end, a systematic review was carried out following the PRISMA checklist and using the Scopus, Web of Science, and PubMed databases. A total of 492 documents were identified and subjected to inclusion and exclusion criteria, of which 27 were included in the quantitative synthesis. As a result, technologies based on gesture recognition for the translation of sign language into speech and vice versa, technologies for sign language teaching, technologies for automatic caption generation, technologies based on online content, and technologies based on text and illumination networks were found in the studies. The findings suggest that there is a need for further research into the motivations for developing sign language technologies, as a contribution to the inclusion of Deaf communities in society without linguistic impositions.

KEYWORDS

inclusive technologies, sign language, Deaf community, deaf people, digital technologies, social inclusion

1. Introduction

Deafness and hearing loss are considered a condition of inability to hear things partially or totally (Abdallah and Fayyoumi, 2016). From a clinical approach, deafness is considered as a disability. From a socio-anthropological approach, the deaf is a member of a minority linguistic community, which speaks a language of its own and its own socio-cultural characteristics. According to Soleman and Bousquat (2021), from a socio-anthropological perspective, the deaf are part of a culture in which they apprehend, collect information and experience the world differently. Thus, the deaf community constitutes its culture and identity in a sense of pride (Becerra Sepúlveda, 2020), which has even encouraged them to claim a social conception and name their deaf condition with the capital letter "D." In this sense, the term deaf is considered from a clinical and oralist approach; and the term Deaf to refer to those whose situation is situated in a linguistic and cultural minority (Solano et al., 2018).

In recent years, Information and Communication Technologies (ICTs) have taken a leading role in society and, consequently, assistive technologies for deaf communication have achieved significant progress (Abdallah and Fayyoumi, 2016). In addition, the advent of the Information Age has made the web and other forms of digital accessibility relevant to multiple everyday processes (Botelho, 2021). These changes favor the establishment of increasingly broader social interactions using mobile devices and computers, which maximize the linguistic and discursive dynamism of language in a digital universe (de Lima Arcoverde. R.D, 2006).

In the educational context, ICTs have been used to support learning processes, prepare teaching material, develop e-learning and web-based environments, create mobile applications, and add value to the education of people with special needs, as is the case of the Deaf community (Samsudin et al., 2017). Furthermore, assistive technologies are fundamental to deaf communication processes in work, educational, and social spheres (dos Passos Canteri et al., 2019).

Deaf people require a variety of accessible teaching strategies based on visual elements and not only on the written word. As Elgaml and Baladoh (2014) explain, most educational resources, including e-learning courses, are written for hearing people, without any adaptation for Deaf students. Therefore, digital media should be made available to Deaf people as well, considering their ways of learning and possible work prospects.

Digital transformation must pay attention to accessibility issues, especially when they involve people with disabilities. For instance, in many regions of Latin America, there is a marked technological inequality that mainly affects the most vulnerable populations (Flórez-Aristizábal et al., 2019). The digital divide is wider in developing countries than in developed ones for reasons ranging from inequality, technological infrastructure, poverty, and educational deficiency to problems of race, gender, and ethnicity, which encompass the current situation of people with disabilities and directly influence their digital exclusion (Berrío Zapata et al., 2021).

However, there are also islands of digital exclusion in poorer or less integrated communities within developed countries. Deaf people belonging to these communities usually find economic and linguistic restrictions, in addition to accessibility barriers (Abascal et al., 2015). Even if they have access to different digital tools that could support their inclusion in society, basic training in sign language, literacy, and digital skills is necessary to use them. Most of the digital tools they have access to are designed for listeners, such as educational platforms, virtual libraries, books and even social networks. The integration of these abilities can be used to ensure access to basic education for marginalized sectors of the population (Abascal et al., 2015). In addition, digital tools should be considered to improve the communication process of Deaf people using sign language translation, given its global reach as a visual-spatial language, and considering the native languages of the Deaf community in each country (Martins et al., 2015).

Therefore, a comprehensive approach to incorporate digital accessibility measures in marginalized populations, such as the Deaf community in developing countries, should include, according to Abascal et al. (2015), new methods for shared access to ICTs; tolerance to technology; simple, inexpensive, and easy-to-maintain technology; and facilities for the use of non-official languages.

Unlike people with other types of disabilities, Deaf communities have sign languages that enable them to communicate not only with other Deaf persons but also with hearing people. The Deaf, as being part of a minority community, do not have many opportunities in different areas, due to the limitation communicating their ideas, since they communicate through sign language, a language that few know. Unlike other disabilities, the deaf have many communication problems with hearing people. Given the importance of these languages, they have been the subject of numerous studies that seek to contribute to the assistance, adaptation, and rehabilitation of Deaf people using digital tools known as assistive or inclusive technologies (Abdallah and Fayyoumi, 2016). Although technologies alone cannot improve complex interaction scenarios for people with hearing impairment, they can help minimize educational and professional barriers that prevent this population from completing, for example, regular educational stages (Prietch and Filgueiras, 2015).

Some studies have used learning platforms (Hernández et al., 2015; Martins et al., 2015) and electronic devices that recognize, translate, and present sign language to facilitate autonomous learning and improve communication, social inclusion, and quality of life of Deaf communities. Other studies have employed mobile applications that help Deaf people communicate with others who have no prior knowledge of the sign language (Abdallah and Fayyoumi, 2016). Such applications are based on the translation of these languages and use inclusive technologies as assistive solutions for sign language recognition (Martins et al., 2015).

Moreover, some studies have considered the position and preferences of individuals with hearing impairments regarding technologies. The study by Findlater et al. (2019) addresses the interest in sound awareness and the preferences for mobile or wearable sound awareness systems for Deaf people. The results of this study revealed "a strong preference for having both haptic and visual feedback, the latter particularly for captions, with the most preferred device design being haptic notifications on a smartwatch and visual information on a head-mounted display or smartphone."

Digital technologies can, therefore, be used as instruments of appropriation of sign language (in educational processes, for example). They also open possibilities for new constructions of a space of appropriation that is increasingly being explored in the training of Deaf people, given its assembly nature (de Lima Arcoverde. R.D, 2006). In addition, the findings of the studies in this field denote the importance of cultural and social considerations for the successful adoption of these types of technologies.

Addressing the problems of a group of people with disabilities by using a single device represents an enormous research and development challenge. In fact, many solutions have been proposed separately for people with hearing, speech, and visual impairments. However, the study by Karmel et al. (2019) presents an assistive device based on the Internet of Things that offers image-to-text conversion and speech synthesis. In addition, it converts the speech recorded by the microphone into text that is then displayed on the screen as a pop-up window for the user to read it. The purpose of these types of multimodal technologies is to give people with disabilities independence and confidence in seeing, hearing, and speaking for themselves by means of assistive technologies.

The studies mentioned above have made it clear that Deaf people face many difficulties in their daily lives, given their inability to communicate with people who do not understand sign language (Yaganoglu, 2021). These difficulties may affect their personal and work life and hinder their academic development (Prietch and Filgueiras, 2015). The studies also highlight the need for assistive technologies that allow Deaf communities to communicate effectively with those who do not use the same language, not to mention their difficulty to learn to read and write.

Based on the above, some researchers have focused on developing inclusive digital tools that meet the needs of Deaf people (Martins et al., 2015; Prietch and Filgueiras, 2015; Abdallah and Fayyoumi, 2016; Findlater et al., 2019). Consequently, they have identified barriers for the Deaf community to access certain technologies, as well as a latent need to communicate with hearing people without the obligation to learn their language and without compromising their own.

The objective of this systematic literature review is, therefore, to identify assistive technologies that include sign language and facilitate and promote communication between Deaf and hearing communities. In addition, it would be useful to identify research gaps and create a roadmap for future research in this field. As a result, we addressed the following research questions:

1. What types of assistive technologies facilitate and promote Deaf people's communication?
2. In which geographical contexts are assistive technologies proposed to facilitate and promote communication in sign language?
3. What can be the future lines of research in this field?

2. Method

This study consisted of a systematic literature review using the Preferred Reporting Items for Systemic Reviews and Meta-Analyses (PRISMA) checklist. Following Hutton et al. (2016), "the PRISMA statement is a guide on research publishing designed to improve the integrity of reporting systematic reviews and meta-analyses" (p. 262). This statement helps researchers improve the presentation of systematic literature reviews by laying out guidelines for planning, preparing, and publishing them (Moher et al., 2014). The statement consists of a checklist that includes 27 items summarized in four phases: identification, screening, eligibility, and inclusion. Based on the above, we established the following parameters:

2.1. Inclusion and exclusion criteria

To identify the articles most relevant to the objective of this research, we conducted three eligibility review rounds in titles, abstracts, keywords, and full texts. The inclusion and exclusion criteria can be found in Table 1. We sought to include only research articles on deafness as a condition to be studied and on the use of assistive technologies to improve the interpretation, communication, and social interaction between Deaf and hearing communities. The articles should also respond to the need for accessibility, considering free and low-cost resources, according to the claims of each of the authors proposing the technology, e.g., access through an institution or free access through a web page, patent release, low cost of materials, among others. We did not consider publications other than articles because, as Dyzel et al. (2020) explain, they might be in the prototype phase and lack validity if they are not tested in daily care settings. The publication period and language were not taken into account.

TABLE 1 Inclusion and exclusion criteria.

Exclusion criteria	Inclusion criteria
Other types of disabilities other than deafness	Diagnosis falling within the spectrum of deafness regardless of etiology
Assistive technologies developed to improve autonomy or hearing	Assistive technologies intended to improve communication and interpersonal and social interaction
Assistive technologies classified as medical devices, hearing aids, and cochlear implants	Assistive technologies that integrate sign language
Assistive technologies of a private nature or not based on sign language	Assistive technology of an accessible nature
Abstracts, conference proceedings, book chapters, or research books	Scientific articles

2.2. Information sources

In this section, we should describe all information sources used in the search, as well as the last search date. The sources of information include databases and contact with study authors to identify additional studies (Hutton et al., 2016). Considering the complexity of the study population and the variety of assistive technologies, we combined technical, medical, and social science research fields (Dyzel et al., 2020). Consequently, we selected databases relevant to these fields, namely, Scopus, Web of Science, and PubMed. Finally, we conducted the search in May 2022.

2.3. Search strategy

In the words of Welch et al. (2016), we should present an electronic search strategy for every database, including any limits used, so that there are no repetitions. This search strategy is typically based on the terms used. In the present study, we conducted the search in titles and keywords for the most part; however, on the PubMed database, we also considered abstracts. The terms used were synonyms for *deafness*, *assistive technologies*, and *digital tools*. Additionally, we included Boolean operators to build the strings and refine the search. We used AND to combine terms, OR to include search synonyms, and * when appropriate. The search strings employed on each database are shown below:

Scopus: TITLE ((deaf* OR "hard of hearing" OR "hearing-impaired" OR "unhearing" OR "unable to hear") AND (("assistive technologies" OR (assistive AND techno*) OR (digital* AND (tool OR tech*))))) OR KEY ((deaf* OR "hard of hearing" OR "hearing-impaired" OR "unhearing" OR "unable to hear") AND (("assistive technologies" OR (assistive AND techno*) OR (digital* AND (tool OR tech*)))))

Web of Science: (TI=(((deaf* OR "hard of hearing" OR "hearing-impaired" OR "unhealing" OR "unable to hear") AND (("assistive technologies" OR (assistive AND techno*) OR (digital* AND (tool OR tech*))))))) OR AK=(((deaf* OR "hard of hearing" OR "hearing-impaired" OR "unhealing" OR "unable to hear") AND (("assistive technologies" OR (assistive AND techno*) OR (digital* AND (tool OR tech*))))))

PubMed: ((deaf*[Title/Abstract] OR "hard of hearing"[Title/Abstract] OR "hearing-impaired"[Title/Abstract] OR "unhearing"[Title/Abstract] OR "unable to hear" [Title/Abstract]) AND (("assistive technologies"[Title/Abstract] OR (assistive[Title/Abstract] AND techno* [Title/Abstract]) OR (digital*[Title/Abstract] AND (tool[Title/Abstract] OR tech* [Title/Abstract]))))).

2.4. Selection process

We obtained a total of 576 records: 360 from Scopus, 44 from Web of Science, and 172 from PubMed. However, we removed 84 duplicate publications after a review in Microsoft Excel® and analyzed the remaining 492. First, we filtered out conference proceedings, book chapters, and publications other than scientific articles. Then, we reviewed the title, abstract, and keywords of each article to exclude those related to conditions other than deafness. Subsequently, we removed the publications that proposed assistive technologies for speech rehabilitation, as well as those about hearing aids and cochlear implants. Afterward, we reviewed the full texts to ensure that the technologies selected were accessible and affordable so that they could meet the needs of the vulnerable populations in which the world's Deaf communities are generally immersed. Three reviewers were responsible for reviewing article by article to identify whether the proposed technology could be freely available or was a low-cost technology. At this point, we had 57 records left. Finally, we excluded 30 more articles because they were literature reviews or analyses of factors that influenced the intention to use inclusive technologies, which did not propose any new technology. The researchers omitted these studies on the premise that investigations of correlation of variables and acceptance of technologies did not respond to the objective of this study. As a result, we obtained a total of 27 eligible records. Figure 1 summarizes the process followed to select the articles relevant to the objective of this study.

3. Results

We considered a total of 27 articles that propose assistive technologies to facilitate and improve Deaf people's communication. Each of the selected articles is subjected to an analysis to answer the research questions: the types of technologies that exist to date through a thorough analysis by the researchers, the geographical context that can be obtained from the metadata generated by the databases selected in the affiliation of the researchers, and the future lines of research, based on the analysis of gaps that are evident in the review.

The results of this study aim to answer the research questions concerning the types of technologies found and the geographical context in which they are proposed. To this end, we characterized the studies according to the type of technology proposed, the country where it was developed, the considered benefits, and the Technology Readiness Level (TRL). These levels were assigned based on the definitions originally proposed by NASA and that have been implemented in different non-aeronautical projects. According to Héder (2017), the TRLs are classified as follows:

TRL 1. Basic principles observed.
TRL 2. Technology concept formulated.
TRL 3. Experimental proof of concept.
TRL 4. Technology validated in laboratory.
TRL 5. Technology validated in relevant environment.
TRL 6. Technology demonstrated in relevant environment.
TRL 7. System prototype demonstration in operational environment.
TRL 8. System complete and qualified.
TRL 9. Actual system proven in operational environment (competitive manufacturing).

Thus, all technologies were assigned to a TRL based on an analysis performed by the researchers according to each author's description of the state of the technologies. We grouped the different types of technologies according to their similarities in terms of purpose, design, and use. The researchers decided that rather than describing each of the functionalities of the technologies, it would be more appropriate to group them according to their functionality. In that way, technologies for sign language interpretation, sign language training, automatic text generation, digital content for the Deaf, and with functionality for mobile devices in text and lighting networks are grouped together.

Therefore, we were able to determine that most of the proposed technologies were based on *gesture recognition for the translation of sign language into speech and vice versa* (see Table 2). These tools favor the communication between Deaf people and hearing people who do not use sign language, so they can be implemented in educational, work, and social contexts. This type of technology has received particular interest from researchers because it addresses an essential need of the Deaf community; consequently, there is a current trend to develop similar tools.

We also identified developments focused on *sign language teaching* (see Table 3), such as dictionaries, encyclopedias, courses, and games. These resources not only support the learning process of Deaf individuals, but also of their relatives, friends, and teachers. Although this type of technology can be used by most people, it is primarily designed for Deaf children.

Similarly, we found a type of technology for *automatic caption generation* (see Table 4) with applicability to mobile devices. Considering that Deaf people usually experience difficulties

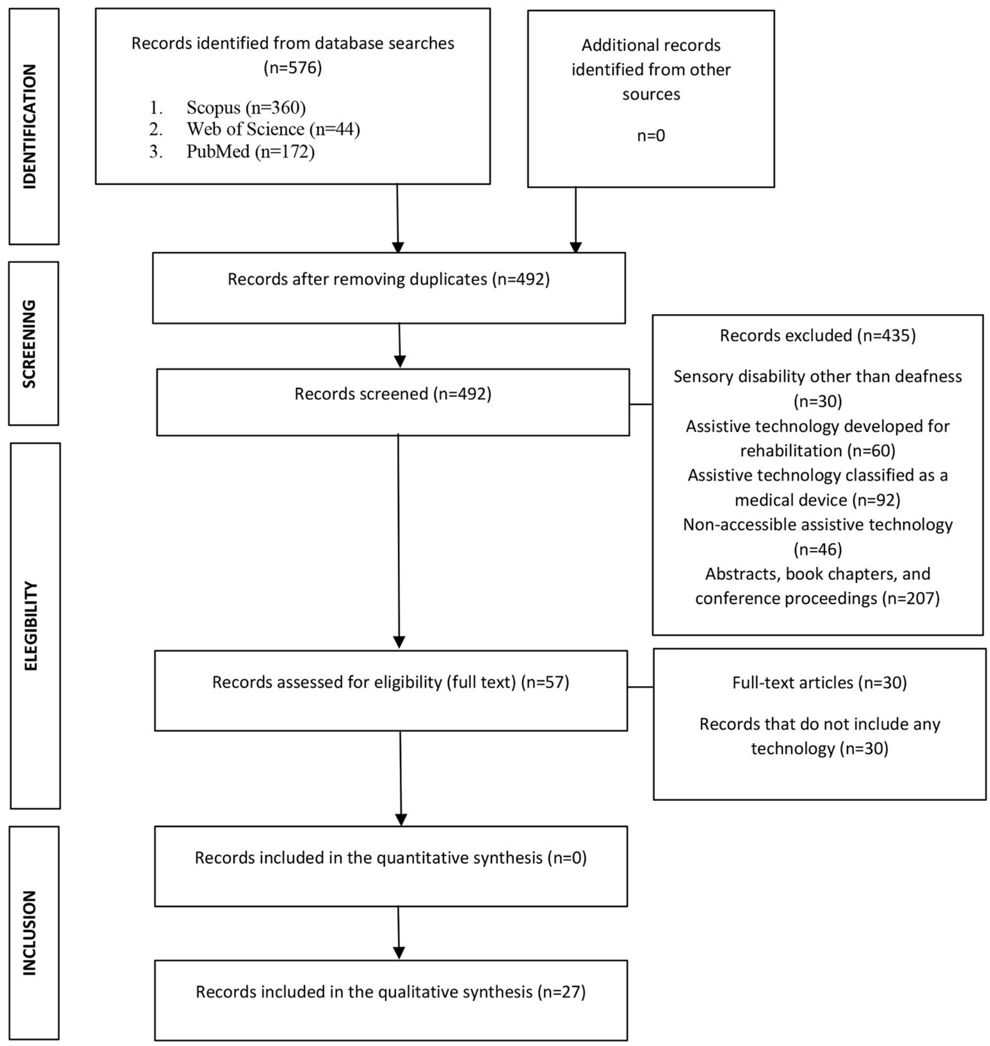

FIGURE 1
Flow diagram of the identification and selection process.

during telephone conversations, these technologies automatically recognize speech and convert it into text, thus facilitating their communication. Visual content can make information more accessible to people with hearing impairment, but particularly to those who understand the written language of their country. In this sense, this technology is not useful to Deaf individuals who understand only sign language.

Some authors have also proposed technologies based on *online content* and *courses* (see Table 5). These technologies are interesting because they make available to Deaf people (in sign language) topics of general interest related, for example, to health or the use of mobile devices. In addition, e-learning technologies are increasingly being implemented in educational processes with significant advances in ICTs. Therefore, they represent an opportunity for Deaf people to access inclusive education, considering their availability, accessibility, usability, and affordability.

Lastly, we identified *text-based technologies* supported by mobile devices and *illumination-based communication networks* (see Table 6). These technologies are useful because communication *via* mobile devices has facilitated the interaction of Deaf people with other Deaf and hearing people, especially thanks to the boom in the use of social networks by this community.

The studies analyzed were carried out mainly in *Brazil* and the *United States* (eight records for each country); therefore, they are the reference contexts for the development of assistive technologies for the Deaf community. The technologies developed in Brazil offer translation of Brazilian Sign Language (Libras) into speech and vice versa, automatic caption generation for television and online content, and courses in sign language to contribute to the accessibility of the Deaf community to online training. Similarly, the technologies developed in the United States focus on offering translation of American Sign Language into English by means of systems ranging from web and mobile applications to gloves. They also produce educational content to be shared online with the Deaf community.

We also found a relevant number of studies in *India* and *Saudi Arabia*, which have also developed technologies for gesture

TABLE 2 Technologies based on gesture recognition for the translation of sign language into speech and vice versa.

Authors	Technology	Readiness level	Country	Benefits
Gupta et al. (2022)	Online sign language translation platform—Gesture recognition	TRL 7 prototype	India	It transforms sign language into speech. It can be used by Deaf and hearing people to exchange ideas
Dignan et al. (2022)	Gesture recognition system	TRL 6 prototype	United States	It proposes a hybrid approach that takes advantage of low-cost sensory hardware and combines it with a smart sign-recognition algorithm to develop a more efficient gesture-recognition system
Areeb et al. (2022)	Hand gesture recognition models to predict emergency signs	TRL 6 prototype	India	It helps people with hearing impairment in emergency situations. It can be used with other sign languages
Alkhalifa and Al-Razgan (2018)	Bilingual (Arabic/English) smartphone-based hearing aid application - *Enssat*	TRL 7 prototype	Saudi Arabia	It supports real-time transcription, real-time translation, and alert management for sign language translation
De Martino et al. (2017)	Automatic Brazilian Portuguese-to-Libras translation system	TRL 6 prototype	Brazil	It aims to improve the bilingual education experience for deaf children, facilitating the understanding of written Portuguese and fostering sign language proficiency
El-Gayyar et al. (2016)	Arabic speech-to-Arabic Sign Language translation application based on cloud computing - *ABTS-ArSL*	TRL 7 prototype	Saudi Arabia	It aims to assist deaf individuals to communicate effectively with the great public to gain a better social life
de Araújo et al. (2013)	Architecture for machine translation to Libras - *LibrasTV*	TRL 9 available	Brazil	It can be integrated and implemented in digital TV systems, a real-time and open-domain scenario
Sarji (2008)	Smart glove that can recognize basic hand gestures and convert them into speech - *HandTalk*	TRL 6 prototype	United States	It is a low-cost system that demonstrates that embedded systems do not have to be expensive to be effective
Su et al. (2001)	Recognition of 3D arm movements involved in Taiwanese Sign Language	TRL 6 prototype	Taiwan	It can classify different types of arm movements by comparing cumulative similarities. It facilitates communication between Deaf and hearing people
Parthasarathy et al. (2022)	Wearable continuous gesture-to-speech conversion system	TRL 6 prototype	United States	It facilitates communication between hearing people (untrained in sign language) and people with hearing impairment. It is a low-cost device
Kushalnagar et al. (2019)	Video remote interpreting technology	TRL 7 prototype	United States	Healthcare and rehabilitation providers may choose to provide VRI over traditional in-person interpreters due to cost and flexibility
de Araújo et al. (2014)	Software components for automatic generation and insertion of sign language video tracks into captioned digital multimedia content	TRL 7 prototype	Brazil	It has a set of mechanisms that use human computation to generate and maintain linguistic constructions. It can be used on digital TV, digital cinema, and web platforms

recognition and mobile applications for sign language teaching. Finally, *Colombia*, the *United Kingdom*, *Sweden*, and *Taiwan* have one study each. These countries have shown interest in sign language translation, digital content creation, and text-based technologies for mobile devices.

The participation of different countries gives us an overview of the development of assistive technologies for the Deaf community around the world. Most of the technologies analyzed have been developed in the Americas, mainly in Brazil and the United States. On the European continent and in the Spanish-speaking countries of Latin America, we identified a few technological developments. The participation of Asian countries is relevant, although we did not find developments in countries with strong economies, such as China, South Korea, and Japan.

On the other hand, future lines of research could focus on the design and development of inclusive technologies in different scenarios, for example, labor and social. In this way, labor adaptation technologies for the Deaf could be proposed, such as a sign language interpreter for each organization, alert systems for meetings and other work tasks, social networks for the Deaf, among others. In addition, the design of inclusive technologies based on sign language for different age groups such as adults should be considered and could be addressed in future research.

4. Discussion

The integration of sign languages into the design and development of communication technologies denotes recognition of the right to autonomy and respect for the Deaf culture. In this sense, as Llamazares de Prado (2021) stated, the use of inclusive technologies favors the democratization of culture and access to information regardless of where in the world one lives, in an increasingly globalized society with multiple forms of communication. For this reason, it is important that deaf communities all over the world have access to low-cost or free inclusive technologies.

TABLE 3 Sign language teaching technologies.

Authors	Technology	Readiness level	Country	Benefits
Pontes et al. (2020)	Educational game to teach numbers in Libras—*MatLIBRAS Racing*	TRL 7 prototype	Brazil	It bridges the gaps between Deaf and hearing students in academic environments. It motivates the learning and reproduction of natural numbers in BSL through entertainment and competition. It can be used with other sign languages
Joy et al. (2018)	Bilingual mobile dictionary for Indian Sign Language - *SignDict*	TRL 9 available	India	It has features for converting camera-captured text into sign language and translating simple sentences from a spoken language into their corresponding signs. The availability of SignDict as a mobile application will help to extend learning outside classrooms and peer groups. It will also make learning possible for parents of Deaf children and other learners
Joy et al. (2019)	Sign vocabulary learning application—*SiLearn*	TRL 7 prototype	India	It is very effective in sign vocabulary development. It can enhance vocabulary learning rate considerably
Meinzen-Derr et al. (2016)	Augmentative and alternative communication technology for enhancing language development of Deaf children	TRL 7 prototype	United States	It supports continued and rapid language growth among elementary school-age children who are deaf or hard of hearing with language underperformance
Capovilla et al. (2003)	Brazilian sign language digital encyclopedia	TRL 9 available	Brazil	It includes a sublexical-component indexing system and a menu-based sign-retrieval system. These allow deaf users to locate specific signs based on five parameters: hands, fingers, place, movement, and facial expression. It takes sign language dictionaries beyond the traditional alphabetical indexing of glosses

TABLE 4 Automatic caption generation technology.

Authors	Technology	Readiness level	Country	Benefits
Zekveld et al. (2008)	Automatic caption generation system to improve telephone communication	TRL 7 prototype	Netherlands	Uses an online automatic speech recognition system

TABLE 5 Technologies based on online content.

Authors	Technology	Readiness level	Country	Benefits
Flórez-Aristizábal et al. (2019)	Digital interactive storytelling for digital literacy	TRL 7 Prototype	Colombia	It supports the creation of all kinds of stories through Deaf children's imagination. It can positively influence the mood of the students. It motivates and engages children in literacy learning
Carvalho et al. (2019)	Online courses	Available	Brazil	It supports nursing care for people with disabilities
de Carvalho and Manzini (2017)	Course using augmented reality technology	Available	Brazil	It can bridge the gaps in the literacy process of Deaf students. It enhances the process of appropriation of relationships and, thus, broadens the communicative repertoire of this population
Áfio et al. (2016)	Online course	Available	Brazil	It is an accessible online course targeted at Deaf people
Dahm and Reese (2021)	Inclusive online learning environment	TRL 6 Prototype	United States	It helps to close the information accessibility gap in libraries
Boudreault et al. (2018)	Online video material	Available	United States	It makes genetic education materials available to Deaf people online and in sign language

In recent years, assistive technologies have been intended to improve Deaf people's communication and interaction. The analysis of the contribution of these tools to society has gone beyond the technical and practical aspects. For example, in their study, Dyzel et al. (2020) analyzed assistive technologies for people with hearing or visual impairment in terms of purpose, design, development, acquisition, implementation, and impact. This demonstrates the researchers' interest in assessing these technologies from their potential to improve the psychological wellbeing and quality of life of people with special needs, as well as the barriers to access. Likewise, in this study, we are concerned that the selected technologies respond to the needs for accessibility of a

TABLE 6 Technologies based on text and illumination networks.

Authors	Technology	Readiness level	Country	Benefits
Roos and Wengelin (2016)	Text-telephone technology	Available	Sweden	It contributes to improving the self-esteem, equality, and independence of Deaf people It facilitates interaction between Deaf and hearing people
Spicer et al. (2009)	Text telephones designed for people with impaired hearing	Available	United Kingdom	It facilitates communication It meets the communication needs of users with impaired hearing
Hinman et al. (2003)	Talking lights illumination-based communication networks to enhance word comprehension by Deaf people	TRL 7 prototype	United States	It modulates ordinary fluorescent lighting to carry an assistive data signal throughout a room while causing no flicker or other distracting visual problems

global community that, from a general perspective, has problems in accessing this type of resources, given its socioeconomic vulnerability condition (Alshawabkeh et al., 2021).

In the same vein, Sousa et al. (2019) explain that accessibility and usability are fundamental aspects of assistive technologies for Deaf people. Accessibility is paramount to understanding information. Accessible formats include, among others, sign language and captions, which have a direct impact on the usability of this type of technology. However, it contrasts with reality.

In recent years, numerous studies on inclusive technologies have investigated the development of skills related to oral communication. As a result, there is an important number of technologies based on cochlear implants and other devices that help improve hearing and support speech rehabilitation and lip movement recognition. However, in this study, we sought to identify assistive technologies based on sign language to enhance Deaf people's communication through digital literacy. As Flórez Aristizábal et al. (2017) state, there is a clear need to conduct more studies and develop more technologies that promote the use of sign language and ICTs in educational environments, especially for children, given the importance of learning processes at this stage of life. Such studies and developments should also encourage the use of digital assistive tools inside and outside the classroom to facilitate communication between Deaf and hearing people.

Along the same lines, using assistive technologies to teach sign language at different academic levels is necessary and beneficial not only to students but also to teachers and relatives. Furthermore, following Llamazares De Prado and Arias Gago (2020), the adoption of hybrid technology approaches under the principles of universal design can help integrate access to education and sign language literacy. Therefore, Deaf communities require assistive technologies based on sign language that can be implemented in different contexts.

Although a considerable number of technologies are targeted at Deaf students, there is still a pressing need to adapt workspaces with assistive technologies for Deaf adults. Alshawabkeh et al. (2021) explain that the currently available tools are insufficient to meet the needs of Deaf people in the workplace. Such technologies should also favor the use of sign language with universal applicability. This summarizes the possible future lines of research in this field, thus answering the third research question.

One of the difficulties in conducting research on the Deaf community is the diversity of needs that surround it. In fact, most of the assistive technologies that we identified in this study are in a prototype phase. In addition, we must consider the financial factor because developing accessible, sustainable, and implementable technologies is costly and time-consuming.

This study addressed general issues of assistive technologies: integration of sign language, accessibility, and improved communication between Deaf and hearing people. These types of technologies empower Deaf communities to express their needs and rights, strengthen their culture, and actively participate in a new society that does not impose its language.

The results of this study provide an overview of the technological options currently available to Deaf sign language users. They can be useful to private organizations, educational institutions, governmental entities, and, in general, to all individuals and organizations involved in the development of assistive technologies based on sign language. The findings also reveal the need to review and analyze government policies and strategies for the development, generation, dissemination, and promotion of these tools.

5. Conclusions

The objective of this study was to identify assistive tools and systems targeted at Deaf communities. We selected 27 articles that proposed different types of technologies to facilitate and improve communication between Deaf and hearing people, that is, technologies for sign language teaching, technologies for automatic caption generation, and technologies based on online content, text, illumination, or gesture recognition for the translation of sign language into speech and vice versa.

Most of the technologies described are in a prototype phase at the final readiness levels. This may be due to financial reasons because these projects are typically expensive, time-consuming, and difficult to run, given the context and needs of this community. In addition, researchers usually need to understand sign language to develop technologies of this type. In this sense, we highlight the efforts made in Brazil and the United States.

The findings of this study suggest that there is a need for further research on the motivations for developing inclusive technologies based on sign language and targeted at the world's Deaf communities. These technologies should also strengthen the teaching of sign language to Deaf children with the support of digital tools and the technological adaptation of workspaces for Deaf adults. Furthermore, researchers should also consider variables such as the communication systems available; the learning abilities of the different Deaf individuals; and the usability, accessibility, utility, and acceptability of the assistive systems and tools to be developed.

The development of assistive technologies based on sign language contributes to the inclusion of the Deaf community in society and strengthens its culture and identity. In addition, it addresses real needs of this population and transforms linguistic imposition into respect for the Deaf culture, integrating it into educational, work, and social contexts.

5.1. Limitations

Assistive technologies do not ensure the full inclusion of the Deaf community in society. In fact, not all individuals have access to these tools. Although we sought to select low-cost or free technologies, they are usually accessed only in the countries where they were developed; therefore, they need to be disseminated so that they can reach the people who really need them. Consequently, the lack of information prevents Deaf people from benefiting from these resources. Moreover, most of the technologies described in this paper are not yet fully developed, so we still must wait for these projects to be successfully completed and to benefit the people for whom they were designed.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

PR-C and YO performed the formal analysis and data curation. AV-A and OP-T performed the conceptualization, methodology, and funding acquisition. PR-C and RT performed the validation and wrote the first draft of the manuscript. All authors contributed to review, visualization, editing, and read and agreed to the published version of the manuscript.

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Conflict of interest

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

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