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Designing electronic graphic symbol-based AAC systems: A scoping review.

Part 1: System description

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Designing electronic graphic symbol-based AAC systems: A scoping review. Part 1: System description

Purpose: This is the first of two papers summarising studies reporting on the design of electronic graphic symbol-based augmentative and alternative communication (AAC) systems, in order to determine the state of the field. The aim of this paper was to provide an overview of the general characteristics of the studies and to describe the features of the systems designed.
Methods: A scoping review was conducted. A multifaceted search resulted in the identification of 28 studies meeting the selection criteria. Data was extracted relating to four areas of interest, namely (1) the general characteristics of the studies, (2) features of the systems designed, (3) availability of the systems to the public, and (4) the design processes followed. In this paper, findings relating to the first three areas are presented.
Results: Most study authors were affiliated to fields of engineering and/or computer science and came from high-income countries. Most studies reported the design of AAC applications loaded onto mobile technology devices. Common system features included customisable vocabulary items, the inclusion of graphic symbols from both established AAC libraries and other sources, a dynamic grid display, and the inclusion of digital and/or synthetic speech output. Few systems were available to the public.
Conclusions: Limited justifications for many of the complex design decisions were provided in the studies, possibly due to limited involvement of rehabilitation professionals during the design process. Furthermore, few studies reported on the design of graphic symbol-based AAC systems specifically for middle- and low-income contexts and also for multilingual populations.

Keywords: assistive technology, augmentative and alternative communication, design, electronic AAC systems, graphic symbols.

Introduction

Persons with complex communication needs (CCN) typically benefit from augmentative and alternative communication (AAC). Electronic graphic symbol-based (GS-based) AAC systems are a form of assistive technology employed to improve communication and participation of children and adults with CCN who are not literate [1–4]. Such systems consist of (a) graphic symbols[1] such as line drawings or photographs that encode words, phrases, or messages; and (b) an interface that displays these symbols and allows a person using the system to access them in some way, for example, by touching or selecting symbols using switches or a cursor. Many (but not all) electronic systems also provide voice or speech output, either in the form of synthetic speech or recorded (digital) speech [5-7]. Systems with the latter capability are also referred to as speech generating devices (SGDs). Designing GS-based systems requires making a number of design decisions about the vocabulary to be made available, the types of graphic symbols used, the meaning units to be represented by these symbols, and the way the symbols are organised on the interface. In contrast to an orthography-based system, where the relationship between orthographic symbols and the linguistic unit is standardised according to the writing conventions of the language in question, graphic symbols are a non-standard and mostly incomplete representation of language. Designers are typically forced to engage in trade-offs between the breadth of messages and vocabulary that are being made available and the learning demands that extensive systems pose [6].

This paper is the first of two to describe the results of a scoping review of the literature that describes the design of electronic GS-based AAC systems. In this paper, we provide general information about the studies and then describe the systems that were designed, with specific focus on the included vocabulary, graphic symbols, interface, access methods and the voice output possibilities. The availability of the systems to consumers is also described. In the second paper [8], the design process is described in more detail and the extent to which this process aligns with the

[1] The term 'graphic symbol' is used in this article to describe two-dimensional representations that take the form of pictures or line drawings [9,10]. This definition therefore encompasses a wide range of more or less linguistic representations but excludes traditional orthography. For a detailed classification of aided symbols used in the field of AAC please see Pampoulou and Fuller [10].

principles of human-centred design is considered. The study is framed by a brief overview of GS-based systems, including their implementation, their components, and recent developments.

Implementation of GS-based systems

Graphic symbols are representations of language concepts and have been used in the field of AAC for many decades [11]. GS-based AAC systems may serve a variety of purposes, such as supporting comprehension and expression as well as behaviour and organization [2,12]. In young children with CCN whose receptive language is developing relatively age-appropriately, GS-based AAC systems have been used with the primary purpose of supporting their expressive communication [13]. There are numerous studies that attest to positive outcomes for individuals who received intervention using GS-based AAC systems, including electronic systems. Gains have been noted in the realm of semantics (e.g., receptive and expressive vocabulary), pragmatics (e.g., increased turn-taking), and morpho-syntax (e.g., increased length of utterance and morphological complexity) [14,15].

In spite of the positive outcomes reported in various studies, GS-based AAC systems are not always perceived as helpful, useful or usable by the intended beneficiaries, and rejection and abandonment have been reported in the literature [16]. Abandonment rates of AAC systems between 31% and 60% have been reported [17,18]. While a variety of complex factors contribute to the rejection and abandonment of GS-based AAC systems, various characteristics of the AAC system itself have been noted to play a role [19,20.

Components of GS-based systems and design considerations

As previously described, an electronic GS-based AAC system has an interface displaying graphic symbols that can be selected by the user. While some controversy exists regarding the exact definition of the term ‘graphic symbol’ [cf. 21,7], we use it to denote pictures (including photographs) or line drawings used in the field of AAC to represent a word, concept, or phrase. Electronic systems may also have speech output capabilities by which the language unit is made audible once the symbol is selected. In order for the system to be usable and useful, aspects like portability, durability, and ease of access need to be considered in the design of the hardware, while aesthetics can enhance the desirability [22] and reduce stigma [23]. Access possibilities include those that require the user to directly select and activate a specific symbol, for example, using a finger to activate a symbol on a touchscreen, or using eye gaze to select a symbol with the help of an infrared video camera [5]. A user may also control a cursor with the help of a mouse of joystick to make direct selections. Scanning, in turn, does not require the motor control that direct selection requires. Symbol options are highlighted in turn by the device and the user activates a switch when the desired option is highlighted [5]. Pampoulou and Fuller [7] further distinguish between selection that is unaided (i.e., requires only a body part such as a finger) versus selection that is aided (i.e., requires a selection aid such as a mouse of a switch).

Various factors around the language representation system (i.e., the vocabulary items, the graphic symbol, as well as the lay-out and organization of these) as well as the presence and quality of voice output also need to be considered. Some of these factors are briefly described in the following paragraphs.

The preselection of vocabulary that will be made available to the user is one of the most challenging aspects in designing and customising a GS-based AAC system [24]. As natural speakers can select and produce their vocabulary at will and on the spot, designers and practitioners often struggle to predict what vocabulary their clients may find useful in various situations [25,26]. While vocabulary should be immediately useful to enable communication and participation with maximal ease in multiple settings and contexts, it should also in many cases allow for increasingly sophisticated use of language, especially when the language skills of the user are expected to improve or develop [5]. These foci sometimes imply trade-offs, for example, between immediate usability (reduced learning demands) and long-term potential of the vocabulary to support novel utterance generation [5].

A number of different approaches and sources for vocabulary selection have been suggested and debated in the literature. The current state of knowledge in the field suggests that vocabulary needs to be selected from multiple sources [24]. These sources can include core vocabulary lists, developmental word lists (e.g., The MacArthur-Bates Communicative Development Inventories or CDI; [27], the suggestions from parents and other stakeholders, and environmental checklists [5,24,28]. While a preprogramed set of words made available by the developer can be helpful as a starting point, a level of customisation will always be required when adapting a system for a specific user. Just-in-time programming (i.e., programming new vocabulary on the spot) has been shown to be a helpful capability to allow instant and easy programming of relevant vocabulary as needed [29,30].

Regarding graphic symbols, various commercially and freely available graphic symbol libraries have been developed over the years, for example Picture Communication Symbols (PCS), Symbolstix, Widgit and free symbol libraries such as Mulberry symbols, symbols developed by the Aragonese Centre for AAC (also called ARASAAC symbols) and Jellow. Most were originally designed to represent a specific language. For example, PCS, Widgit (developed from the Peabody Rebus Reading Program's symbols), and Blissymbols were originally designed to represent the English language [31,32]. As a result, additional development and adaptations are usually needed before such a symbol system can be used to represent another language, as vocabulary and grammatical elements differ between languages. For example, the agglutinative structure of the

Turkish language makes many of the available symbol libraries unsuitable to adequately represent the language [33]. Furthermore, the visual nature of symbols lends itself to representing concepts in a way that is aligned to a specific geographical context and culture, and this may not translate to other geographical contexts and cultures [33-38]. Food, modes of transport, building styles, weather, clothing, religion and conventions around celebrations (e.g., weddings) are some of the obvious differences between cultures and geographical contexts. As a result, a snow flake may not be a logical symbol to represent the concept ‘cold’ in some countries or regions – to give but one example.

Graphic symbol collections differ on a number of variables, for example, complexity, distinctiveness, figure-ground differential, iconicity, and vocabulary size and representational range [7;21]. These variables influence how easily the symbols are recognised and/or learnt, and also to what extent they allow the user to generate novel utterances [10]. Pampoulou and Fuller [10] suggest that AAC symbols should primarily be classified along a continuum of linguistic properties. According to these authors, non-linguistic symbols like photographs and clip art images do not possess an internal logic by which new symbols can be created. These collections are also used idiosyncratically (i.e., compiled for a specific person) and the number of vocabulary items represented is typically limited. These factors limited the user’s ability to generate a wide range of novel messages. Many symbol collections consisting of line drawings (e.g., PCS and Widgit) are classified as prelinguistic. These symbol collections possess a degree of internal logic, and often represent a wide range of concepts and different parts of speech. They allow the user to generate a variety of utterances and meanings, although they do not give access to the unlimited generativity that a truly linguistic system (such as orthography) offers. The linguistic properties of the graphic symbols designed or incorporated into the AAC system need to be carefully considered to ensure maximal communication autonomy and (specifically in children) language development [10].

Regarding vocabulary organization (i.e., lay-out), visual scene displays (i.e., a highly contextual picture or photograph of a scene with embedded hotspots that contain pre-programmed messages) have been shown to facilitate message retrieval and communication turns in young children as well as adults with chronic severe aphasia [3940]. Visual scene displays have been described as establishing a contextualised, personally meaningful and event-based platform for the exchange of messages that is of benefit to beginning communicators. Grid-based displays are more commonly used for individuals at a higher level of language development than visual scene displays [41]. Theoretically, grid displays do not 'lock' a vocabulary item into a specific context [42] and may therefore encourage more generalised use. According to Beukelman and Light [5], vocabulary items on grid displays have been arranged (a) by category (also referred to a taxonomic organization, e.g., people, food, toys, etc.) ; (b) by schema (e.g. by event, activity or setting); (c) by part of speech (e.g., nouns, verbs, etc.) and/or syntactic category (e.g., subject-verb-object); or (d) alphabetically. In addition, it has been suggested that core vocabulary should be displayed in a prominent location on an AAC system [28]. Often, more than one organizational approach is combined within one system.

Research evidence supporting the choice of a particular organizational approach over another is scarce. Although Fallon et al. [43] found that typically developing children aged 4-5 years tend to organise words by event schema, Light et al. [44] found that they learnt to locate vocabulary items on both schematic and taxonomic grid displays with equal accuracy. Alphabetical organizations rely on phonemic knowledge and are therefore typically not appropriate to preliterate individuals. Thistle and Wilkinson [41] surveyed 112 SLPs on their decision making around AAC display design. They found that grid-based designs were used most often with a strong focus on the consistency of the vocabulary display to capitalize on motor planning. Motor planning and display consistency can reduce learning demands including reducing the overload of working memory [45-47]. It has been noted that schematically organised vocabulary often leads to duplication of vocabulary items in various locations [44].

The voice output of electronic AAC systems can be digital (recorded), synthetic (i.e., computer-generated, also often referred to as text-to-speech technology), or hybrid (combining both synthetic and digitised speech) [7]. Digital speech output requires that a speaking person use his or her voice to record every word or phrase that is to be made available on the system. Preferably, all recordings should be made by the same person in order to give some uniformity, and the voice should be well-matched in terms of age and gender [48]. If the person recording messages is a familiar partner, this may lead to some confusion as the person using the device ‘speaks’ with the partner’s voice. When recordings are made by someone who is not a familiar partner, adding new recordings may be difficult, as this person may not always be available. Programming synthetic speech into a device is not dependent on a specific person, as the message to be spoken by the system is merely typed into the device. Innovations in the methods used to produce synthetic speech have led to a reduction in cost and significant improvements in quality over the last 20-40 years [48]. However, text-to-speech technology has not yet been developed for all languages, partly due to resource constraints [49,50]. Also, for some languages, only adult voices and/or only voices of a particular gender may be available [49]. Tone of voice remains problematic in all synthetic speech, and the person using the system typically cannot choose the emotion or emphasis that is to be conveyed by the voice [48].

GS-based systems: Recent developments

The mobile technology revolution has led to a proliferation of electronic AAC applications and software that can be loaded onto tablets, laptops and mobile phones [51]. Such non-dedicated AAC systems have become more accessible and affordable to many individuals who use AAC when compared to older, dedicated devices [52]. Additional features such as internet access, texting, and social media allow for a wider range of communication opportunities [51]. The use of mainstream devices has reduced stigmatisation of this form of assistive technology [52-54]. In addition, advances in computing have made a number of additional AAC system functionalities and features possible, such as animated symbols, symbol prediction and pop-up windows with grammar and morphology options [55].

The reduced cost and simplification of the design process has democratized the development and access to electronic AAC systems in many ways. Individuals who may not have a high level of expertise in AAC or rehabilitation engineering can now develop AAC systems, and the mainstream availability and relative affordability of both hardware and software has reduced the reliance on healthcare professionals to drive and oversee the acquisition of electronic AAC systems [51,56]. This development has also opened up possibilities for AAC system development in less resourced contexts – both contexts with fiscal constraints and also those with AAC knowledge and expertise constraints. There are indications that AAC systems are being increasingly developed for people from a variety of linguistically and culturally diverse and previously underserved contexts [57- under review].

At the same time, a solid research base to elucidate the interaction between persons with CCN, the AAC system, the partner and the environment is still lacking, and AAC system design remains technology driven rather than research based [58]. As with previously designed AAC systems, AAC applications may improve some aspects of communication for some clients and their partners, but the usability, usefulness and the user experience they offer may not be optimised. When the emphasis remains on the application and construction of the technology, the psychological and sociological impact of the design, and the goodness of fit to the needs, preferences and contexts of a specific population are often ignored [59].

The proliferation of non-dedicated electronic AAC systems and burgeoning developments to design such systems for non-English and preciously underserved contexts suggests that a review of design processes may be a timely endeavour. In this paper, we will provide general backgrounds of the studies. We will also describe the systems that were designed, with specific focus on the included vocabulary, graphic symbols, interface and access possibilities and the voice output possibilities. The availability of the systems to consumers is also considered. In the companion paper, we describe the design approaches and processes used, and the extent to which human-centred design principles were incorporated in the design of new AAC systems. Because design considerations for GS-based systems may differ from those for orthography-based systems, we decided to limit this review to the former type of system.

Method

A scoping review was conducted to identify and synthesise the literature that documents the design of electronic GS-based AAC systems. Scoping reviews summarise the literature more broadly without focusing on a very specific and narrow research question [59]. The scoping review procedure was guided by the methodological framework developed by Arksey and O'Malley [60] enhanced by Levac et al. [61], and the PRISMA extension for scoping reviews (PRISMA-ScR) [62]. However, the optional sixth stage (consultation with stakeholders) of this methodology was not conducted. A review protocol was developed prior to conducting the review.

Search strategy

A multifaceted search strategy was developed by the authors in consultation with a subject librarian. The search aimed to cover literature from all relevant fields, including rehabilitation, education, linguistics, engineering, and computer science. The search methods included the following:

- Electronic database searches (Advanced Technologies & Aerospace Collection, Academic Search Complete, Computer Science Database, Cumulative nursing and Allied Health Literature [CINAHL], Education Collection, Educational Resources Information Centre [ERIC], Health Source: Nursing/Academic Edition, Humanities Index, Humanities Source, IEEE Xplore Digital Library, Library & Information Science Collection, Linguistics Collection, Linguistics and Language Behavior Abstracts [LLBA], MEDLINE, ProQuest Dissertations & Theses Global, PsycARTICLES, PsycINFO, Science Database, Social Science Database, Technology Collection, Springerlink, Taylor & Francis [journals], Wiley Online Library, Web of Science);
- Search using the Google Scholar search engine;
- Hand search of reference list of identified articles.

The electronic database search was conducted on 4 November 2020. A Really Simple Syndication (RSS) feed and search alerts were set up on all databases. Results from these feeds were collected until January 2021.

Pilot searches were conducted to assess the feasibility of the search terms. After refining and adjusting search terms, three search strings were compared between various databases to determine which search string provided relevant results. Relevant databases were then searched using the final Boolean search string: (“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”). Limiters were set on language (English) and date (2000 – present). The databases, search string and yields are provided in Appendix A.

Selection of Studies

Studies were selected according to a list of inclusion and exclusion criteria, that were refined and finalised while piloting these criteria on pilot search results [61]. Table 1 provides the final inclusion and exclusion criteria that was used to select studies for this review. Screening was completed using Covidence, a web-based review platform [63]. Each record was independently screened by the first author and either the second or third author and evaluated for in- and exclusion based on the criteria established. Screening was conducted in two rounds – first on title and abstract level, and then on full text level. The percentage agreement after the independent screening was calculated by dividing agreements by the sum of agreements and disagreements and multiplying by 100. The agreement between the authors was 97.3% for the title and abstract screening, and 83.4% for full text screening. Any disagreements between reviewers were discussed, and consensus was reached as to whether to include or exclude the record.

Data extraction

A data extraction form was developed on Microsoft Excel in accordance with the sub-aims of the study. Data was extracted in accordance with the following categories (a) general characteristics of the studies (authors, date of publication, aim, country in which the development took place) (b) description of the product/prototype that was designed), (c) design approaches used, and (d) human-centred design principles observed in the study. In this paper, the results of data extracted according to categories (a) and (b) are reported. Data was extracted independently by the second author and one of two research assistants, who were qualified speech-language therapists with Master's degrees in AAC. Prior to the data extraction process, the assistants were provided with a verbal explanation of the information required for data extraction, as well as additional written definitions to ensure appropriate understanding of the data to be extracted. The data extracted by the second author and research assistants was compared and the initial agreement on data extraction before reaching a consensus was 89%. The author and the two respective research assistants discussed differences and reached consensus on most aspects, resulting in an agreement of 99.5%. The first author acted as arbitrator in the remaining 0.5% of disagreements. In preparation of this paper, the first author additionally extracted information pertaining to the system designed. The second author independently extracted the same data and an agreement of 99,8% was found. Consensus was reached on disagreements.

Results

Search Results

The results of the search are documented using Tricco et al.'s [62] PRISMA flow diagram structure, as seen in Figure 1. A total of 3628 records were identified through electronic database searches, and an additional 97 records were identified via other sources (hand search and Google scholar search). Once duplicates were removed, 3256 records remained. Of these, 3155 were excluded during title and abstract screening. A total of 101 records were then screened on full text level, and 73 were excluded. A total of 28 studies remained for inclusion in the review. An overview of the studies included is provide in Table 2.

General characteristics

Table 2 provides some general characteristics of the included studies. It is noteworthy that most articles (*n* = 20) were published between 2011 and 2020, while three were published between 2006 and 2010, and two between 2000 and 2005. Most studies included researchers from various disciplines/institutions. Most of the authors were affiliated to departments or schools of computer science, informatics/bioinformatics, and engineering/bioengineering (*n* = 17). Fewer studies had authors affiliated to departments of health and rehabilitation (*n* = 8) and education/special education (*n* = 5).

Studies took place in various locations. A total of 12 studies took place in a European country such as Italy, Croatia, Portugal, Spain, the United Kingdom, and the Netherlands. Fewer studies were based in Asian countries (*n* = 7) such as Japan, China, and India. The remaining studies were conducted in North American (*n* = 5) and South American (*n* = 4) countries. No studies were conducted in any African country or in Australia. A total of 22 studies were conducted in high income countries, whereas five studies were conducted in upper middle income countries and one study in a lower middle income country [64].

AAC Systems Designed

Most of the systems designed (*n* = 26) were AAC applications designed to be uploaded onto commercially available hardware. In 18 studies, the hardware mentioned comprised of a form of mobile technology such as a smartphone, tablet, or personal digital assistant (PDA). Two studies mentioned computers without further specification, while one study mentioned a desktop computer. Five studies that described an AAC application did not specify the hardware on which it was loaded. In 12 studies, specific operating systems were mentioned, including a combination of iOS and Android (*n* = 4), Android only (*n* =4) and iOS only (*n* = 3). The Windows operating system was only mentioned once.

In two older studies, dedicated AAC systems were described. Allen [23] designed the Portland Communication Aid, consisting of a book with keyboard, waist pack, and mobile speaker unit. Hill et al. [65] designed a Mandarin software application for a 128-location speech generating device.

Systems were designed to give access to different languages. English was reported most frequently (n = 7). Spanish (n = 3) and Portuguese (n = 3) were the next most common languages. Systems to give access to expression in Japanese (n = 2), Chinese (n = 2), and Arabic (n = 2) were also reported. Only one study each reported on systems that gave access to Dutch (n = 1), Mandarin (n = 1), Hindi and Bengali (n = 1), and Croatian (n = 1) as languages used by the target population. In six studies, the language associated with the system was not mentioned. Only one system was designed to give access to more than one language, namely Hindi and Bengali [66].

The predetermined vocabulary included within each system was often not explicitly discussed, and hardly any information about the type and number of words/messages and/or parts of speech was provided. However, the incorporation of core words was mentioned by Hill et al. [65]. Al Arifi et al. [67] mentioned including the message ‘I want’ and customisable request items. Cheung [68] reported that vocabulary was categorised by parts of speech. Karita [69] and Rodríguez-Sedano et al. [70] seemed to base their vocabulary on that of other AAC systems. In contrast, the systems’ capability to allow customisation of vocabulary (i.e., the programming of personalised words or messages by users or their partners) was reported in 25 studies. Just-in-time (JIT) programming was mentioned in one study [71]. Karita [69] described a system that automatically changed the available vocabulary based on GPS input. Additional language features such as word or sentence prediction (n = 3) and access to morphology or syntax (n = 3) were also reported.

In various studies (n = 10), authors described including GS from one or more commercially or freely available AAC symbol library such as PCS (n = 4) and ARASAAC symbols (n = 5). Other symbol libraries that were each mentioned once each were Widgit symbols, Sclera, and Mulberry. In nine studies, authors described drawings and pictures from other sources, including GS developed for previous AAC systems (n = 3; i.e., Lingraphica symbols, symbols developed by the Indian Institute of Cerebral palsy, and icons developed for a European AAC system). Images from clipart, web images in general, and images created specifically for the system (e.g., using Corel Draw X7) were also mentioned (*n* = 3). The option for the system user to create drawings or sketches within the AAC system (e.g., on a drawing pad) while interacting with others in order to convey their message was mentioned twice – in both cases as part of systems created for persons with aphasia [72-73]. A total of 19 designed systems incorporated photographs - these included photographs of objects, events or people taken by the individual using the device or retrieved from the internet.

In many of the studies (*n* = 18), authors reported using a dynamic grid display, where selection options were presented in a grid array. Four systems were developed to facilitate storytelling and narration, and therefore made use of images (pictures or photographs) presenting scenes, that were presented in a sequence, for example, by scrolling. Of these, two systems were designed for adults with aphasia [72,74]. In the remaining studies, the lay-out was not clearly described. Visual scenes were not explicitly mentioned.

The size of the symbols and colour coding was only reported in eight and seven studies respectively. Colour coding techniques included the use of the Fitzgerald key to categorise vocabulary, as seen in de Oliveira et al.'s [75] study. Hervás et al. [76] included a similar strategy and coloured coded vocabulary categories that correspond to the respective 'part-of-speech tags' (p. 5653). The authors of five studies reported on additional display features such as the use of bright colours to maintain children's attention [77], categorising pictures based on the time they were taken [72] or changing the graphic symbols based on location [69].

Synthetic or digital voice output as part of the GS-based AAC system were reported by the authors of nine and seven studies respectively. AAC systems that include both synthetic and digital voice output were reported in eight studies. In four studies the type of voice output was not specified.

Regarding access methods, the authors of most studies ($n = 21$) reported using touch screens as a way in which users could access specific graphic symbols on an AAC system. Other access features such as a keyboard ($n = 4$), a mouse ($n = 4$), switches ($n = 3$), eye gaze ($n = 1$), as well as a keypad for scrolling ($n = 1$) were also mentioned.

Evaluation and Availability of the Product

The designed systems were not always final products available to the public, but also included prototypes. Of the products developed, 14 were reported to meet the requirements set out by the researchers, whereas 13 products partially met the target requirements. There was no indication from the studies that any of the products did not meet any of the target requirements. The need to redesign or adjust the products/prototypes designed was reported in eight studies. For example, Karita [69] suggested improvements regarding the user interface and the product usability and Williams et al. [78] reported on refining the input mechanism and vocabulary structure of the system designed.

The availability of the products and/or prototypes designed was not commonly reported. The authors of only eight studies discussed the availability of the products designed, of which four are freely available and two are commercially available for purchase and thus are accessible to the public. The two remaining studies were not as specific. For instance, da Silva et al. [79]reported that their product was available but did not specify whether the product was freely or commercially available, whereas Bhattacharya and Basu [66] stated that the product was deployed at a number of institutions but did not specify if this product was also available for the public.

Discussion

This review underscores the proliferation of GS-based AAC systems designed as applications for mobile technology. The availability, relative affordability, and acceptability of this form of technology make it an attractive choice as a hardware platform for AAC systems [51,53]. It is furthermore noteworthy that, although most studies were conducted in high income countries, six were conducted in upper middle or lower middle income countries. This may be another suggestion that non-dedicated AAC technology may be more affordable and obtainable in contexts that are less resourced.

From the prolific involvement of persons affiliated to departments of engineering and computer science it is clear that these disciplines typically drive the design of GS-based AAC systems. Involvement of rehabilitation specialists in design teams was notably less, in spite of the important role such professionals could play in ensuring that user needs and abilities are considered more broadly (i.e., not only based on a small group of cases). In this way, poor feature matching and system abandonment can be avoided [51]. Some commercially available GS-based AAC systems currently include practitioner-designed features, such as vocabulary sets designed on the Gateway language strategy conceptualised by Bruno [79], and page sets based on the Pragmatic Organization Dynamic Display (PODD) strategy by Porter [81].

While some of the features of designed systems clearly exploited the possibilities of the mobile technology (e.g., the use of the inbuilt camera to take photographs and incorporate these into the AAC system, as well as the use of the GPS system to automatically detect user location and change overlay based on location), the use of more traditional features such as grid displays was still evident in many studies. According to Judge et al. [82] and Light, McNaughton et al. [83], many electronic GS-based systems are based on older paper-based systems, which typically consisted of grid-based displays. It was interesting to note that VSDs were not mentioned, even though these types of displays have been receiving some attention in the recent literature. In some cases, this may suggest that designers take over standard practices without consideration of the latest research evidence [44,51]. Similarly, the potential of the newest technology to simplify certain operational processes in using an AAC system could lead to better system uptake [84].

Limited consideration also seemed to be given to the complex decisions around vocabulary selection and organization of the symbols, possibly reflecting a lack of understanding on the part of the designers. The availability and type of vocabulary is a factor that requires much consideration [53]. This review found that few studies considered the type of vocabulary in terms of the specific words used or grammatical structures (e.g., parts of speech) pre-programmed into the system. However, a positive outcome from this review was that many systems were designed to easily customise vocabulary, which included strategies such as JIT programming.

It is interesting to note that less than half of the developed systems included a specific predeveloped AAC symbol library. Amongst the systems where this was included, the popularity of the ARASAAC symbol library was notable – although it contained (at the time of writing) a smaller number of GS and has been more recently established than older libraries such as PCS and Widgit, the possibility of freely using it under a creative commons license seems to have made it an attractive option. Reason for minimal use of established symbol libraries may have included possible licensing questions and fees, and a lack of appropriateness of the images for the culture, language and context of the intended system users. However, it was nevertheless noteworthy that none of the remaining studies reported any details about the development of an extensive language and culture-appropriate symbol library. Instead, the incorporation of personalised images was often reported – this included generating one's own images using drawing tools, sourcing images from the web and taking photographs with the built-in camera of the device. Personalised AAC systems can better accommodate and reflect each individual's desires, preferences, culture and linguistic background [85-87]. At the same time, abstract vocabulary is usually difficult to represent with the typically more iconic images found on the web or represented by photographs (e.g., it may be difficult to take a photograph that represents ‘have’ or ‘year’). Established AAC symbol libraries with tens of thousands of images representing different words may allow a somewhat more unified approach to represent a larger vocabulary.

Colour-coding GS was reported in some studies. This is a promising result as the colour of symbols and background plays a role in perceptual processes and can contribute to the ease of discriminating, recognising and memorising GS within a system, as well as improve reaction times when locating targeted symbols [88]. This is important as it shows some form of consideration of the individual’s visual and visual processing abilities and an effort to reduce perceptual and cognitive demands.

A total of 17 systems incorporated synthetic speech. This finding reiterates the importance of this technology for electronic AAC systems [5]. It was interesting to note though that, despite the advances in synthetic speech technology, seven systems only incorporated digital speech. These systems were developed to give access to English, Spanish, Japanese and Croatian. Synthetic speech technology exists for all of these languages, although it may not have been developed for the particular operating system at the time the study was conducted. Alternatively, its incorporation may have been too costly or time consuming. The more natural intonation that is possible using digital speech may have been another reason for choosing it. A combination of digital and synthetic speech as reported for eight systems allows for the flexibility to choose which option to use.

Most studies reported a touch screen as an access feature (e.g., the individual can select the relevant GS by touching the screen of the device). A touch screen is a common feature of smartphones and/or tablets. However, few studies reported on additional access features such as eye gaze, switches, and using a mouse to select GS. In light of the possible physical (motor control), visual, and cognitive limitations of the population for whom many of these GS-based AAC systems were designed, one may have expected to find more studies considering these additional access features [5,89].

It is clear from the limited number of available GS-based AAC systems reported within this review that many studies/designs are still ongoing. In addition, despite many systems meeting or partially meeting the requirements set out in the beginning of the design process, numerous studies have suggested recommendations for further development, as well as further research to test and/or improve the designed system. This illustrates the cyclical relationship between research and development that is typical of a design process [90,91].

Limitations

Although this review followed a rigorous search protocol, studies may have been excluded due to various aspects such as the limitation of only sourcing English articles, which may have influenced the number of citations yielded. Additionally, as this review addresses a large, multidisciplinary field, it may be possible that relevant citations may have been reported on databases that were not considered and as a result may have been excluded from this review. Possible exclusion of citations based on the identified search terms must be also acknowledged.

Moreover, considering that design processes are multifaceted, such processes may have been reported in numerous papers. Therefore, some relevant design studies may have been excluded from the review as the individual papers reporting on the process may not have met all the inclusion criteria. For example, a particular record may only have reported on designing one aspect of a GS-based AAC system (e.g., selecting appropriate vocabulary, or designing an appropriate symbol library).

The exclusion of grey literature in the review is another important limitation. Companies developing AAC systems may not have the access, funding, or interest to publish their development processes in peer-reviewed journals as their main mandate is not to produce and disseminate research findings. As a result, the design processes they use would not be documented in peer-reviewed articles.

As this was a scoping review, quality appraisal of included studies was not conducted and thus it is possible that the quality of studies may have varied. In addition, as is typical of a scoping review, many aspects of the included studies were described without going into much depth on any specific aspect. Instead of merely documenting the characteristics of the designed systems, for example, one could consider to what extent these characteristics matched the characteristics of the population, based on previous research on feature matching.

Recommendations for further studies and design projects

The findings of the review suggest that the specific features of the GS-based AAC could be better described in design studies, and that designers may be encouraged to pertinently consider and justify the decisions they make about the vocabulary, the lay-out, the graphic symbols included, the access methods, and the voice output included as part of the system. The findings also suggest that there is a greater need for collaboration between designers and engineers and rehabilitation professionals. Rehabilitation professionals, especially those working in the field of AAC, should be part of the design team as active co-designers. There are a multitude of reasons for this but for the most part, they can guide methods to involve users and stakeholders, suggest relevant outcomes to be evaluated, and may be more skilled at designing research to evaluate performance and obtain social validation. A review of grey literature (e.g., blogs and company websites) as well as interviews with developers and surveys of the industry could further be useful to understand to what extent rehabilitation professionals are already involved in system design and development.

It is clear that most of the design and development work in the field is still conducted in high-income countries. The emerging work in middle- and low-income counties identified in this review is encouraging, but more needs to be done in this regard. More than 80% of the world's population resides in low- and middle-income countries, where risk for and prevalence of disability is significantly higher [92]. High adoption rates of mobile technologies in low and middle-income regions represent an opportunity to facilitate the roll-out of mobile technology-based AAC solutions [93,94]. GS-based AAC systems that are specific and appropriate to the cultures, languages, and contexts of the populations residing in low- and middle- income countries are urgently needed [95]. Similarly, systems that give access to multiple languages need to be designed. Although over half of the world's population is multilingual [96], most AAC systems are designed to only give access to one language.

Conclusion

The identification of 28 studies reporting on the design of a GS-based system is a positive finding, attesting to continued development of this form of assistive technology for the benefit of persons with CCN. The diversity of countries where these design projects were conducted and the diversity of languages for which systems were designed is another positive finding, suggesting that the availability of linguistically and contextually relevant electronic GS-based AAC systems is expanding to previously underserved populations. The proliferation of mobile technology in both high and low resource contexts has created a platform for making such systems more easily available and more affordable. However, it is clear that developments are still primarily taking place in high-resource contexts.

The findings further highlight that GS-based system design remains complex, and that designers are required to take a multitude of factors into consideration. In this paper, we have only focused on the system itself. Even here, many aspects require consideration, such as the vocabulary included, the GS used, the display, the voice output, and access. From the results of this review, it seems that designers do not always report in detail on the way each of these factors is addressed in the design process, and limited justifications are provided for specific design decisions. It was interesting to note that many systems designed seemed to require a fair degree of customisation and programming from the support team of the person using the system, such as, for example, programming the vocabulary to be included, sourcing images from the web or taking personal photographs, and recording the spoken messages associated with the symbol. While such customisation possibilities are positive to ensure an individual good fit between the system and the person using it, this places high demands on the support team. For persons with more advanced language skills, a more elaborate system with a larger preprogramed vocabulary may be desirable.

One has to acknowledge that research to guide GS-based AAC system design decisions is limited [58], and often somewhat ambiguous. While specific design decisions may facilitate one aspect of system use (e.g., the use of VSDs to enhance immediate and contextualised use of a system), the same design decisions may not optimise other aspects of use (e.g., VDSs may not be ideal for generalised and flexible use of vocabulary). Furthermore, research on the effect of different system features on system use may not be readily available and accessible to computer scientists and engineers, as it is published primarily in the rehabilitation, psychology and education literature. There seems to be a measure of disconnect between the publications that focus on system design and those that focus on system use.

One interesting finding was that, despite research attesting to the usefulness of many popular AAC systems sold by the prominent technology companies, information on the design of such systems is not well documented in the literature. While this could be due to various reasons such as patent restrictions, the lack of information about system design precludes designers who wish to design systems for new languages, for example, from learning from the design procedures employed.

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Declaration of interests

The authors report that there are no competing interests to declare.

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Table 1

Criteria for Inclusion of Studies

Aspect	**Inclusion**	**Exclusion**
Population	Persons with CCN. This could include individuals with the following diagnoses: physical disabilities such as cerebral palsy (CP), intellectual and/or developmental disabilities such as autism spectrum disorder (ASD) and Down's Syndrome, as well as acquired disorders such as stroke and traumatic brain injury (TBI) [28,29].	Children/adults without disability. Persons with learning impairments such as dyslexia.
Issue	Describes the design and/or development process of an electronic GS-based AAC system, including the input obtained and an evaluation of the product.	Describes only customisation, testing, or implementation of a GS-based AAC system. Information regarding the design process is not adequately described.
Outcome	The outcome of the design process is an electronic graphic-symbol-based AAC system, defined as any AAC system or AAC application that requires a source of electricity (e.g., battery) to function, and which consists of graphic representations that are organised and displayed on an interface. An individual using the system can access these representations in some way, for example, by touching or selecting symbols using switches or a cursor (Beukelman & Light, 2020). Articles were included even if they reported on the design of multiple products; however, only information pertaining to the design of the GS-based AAC system was considered.	The outcome is any other AAC systems, such as an electronic text-based system, or a non-electronic system. The outcome is only one component of an electronic graphic-symbol-based AAC system (e.g., symbol library, synthetic voice). The outcome (product) is not adequately described.

Table 2

Search Strategy and Number of Citations Generated per Database

Database	**Search strategy**	**Initial yield**	**RSS Feed**	**Total (minus duplicates)**
Scopus	ALL (“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	164	3	146
EBSCOhost (Academic Search Complete, CINAHL, ERIC, Health Source: Nursing/Academic Edition, Humanities Source, MEDLINE, PsycARTICLES, PsycINFO)	TX (“augmentative and alternative communication” OR AAC OR “alternative communication”) AND TX (“design process” OR “development process”)	206	29	91
ProQuest (Education Collection, Humanities Index, Library & Information Science Collection, Linguistics Collection, ProQuest Dissertations & Theses Global, Science Database, Social Science Database, Technology Collection)	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	271	24	216
IEEE Xplore Digital Library	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	1065	7	1065
Taylor & Francis (journals)	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	267	2	215
Wiley Online Library	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	247	10	207
Computer Science Database	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	676	-	670

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Database	**Search strategy**	**Initial yield**	**RSS Feed**	**Total (minus duplicates)**
Linguistics and Language Behavior Abstracts [LLBA]	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	19	-	19
Advanced Technologies & Aerospace Collection	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	127	-	97
Springerlink	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	560	-	488
Web of science	(“augmentative and alternative communication” OR AAC OR “alternative communication”) AND (“design process” OR “development process”)	26	-	22

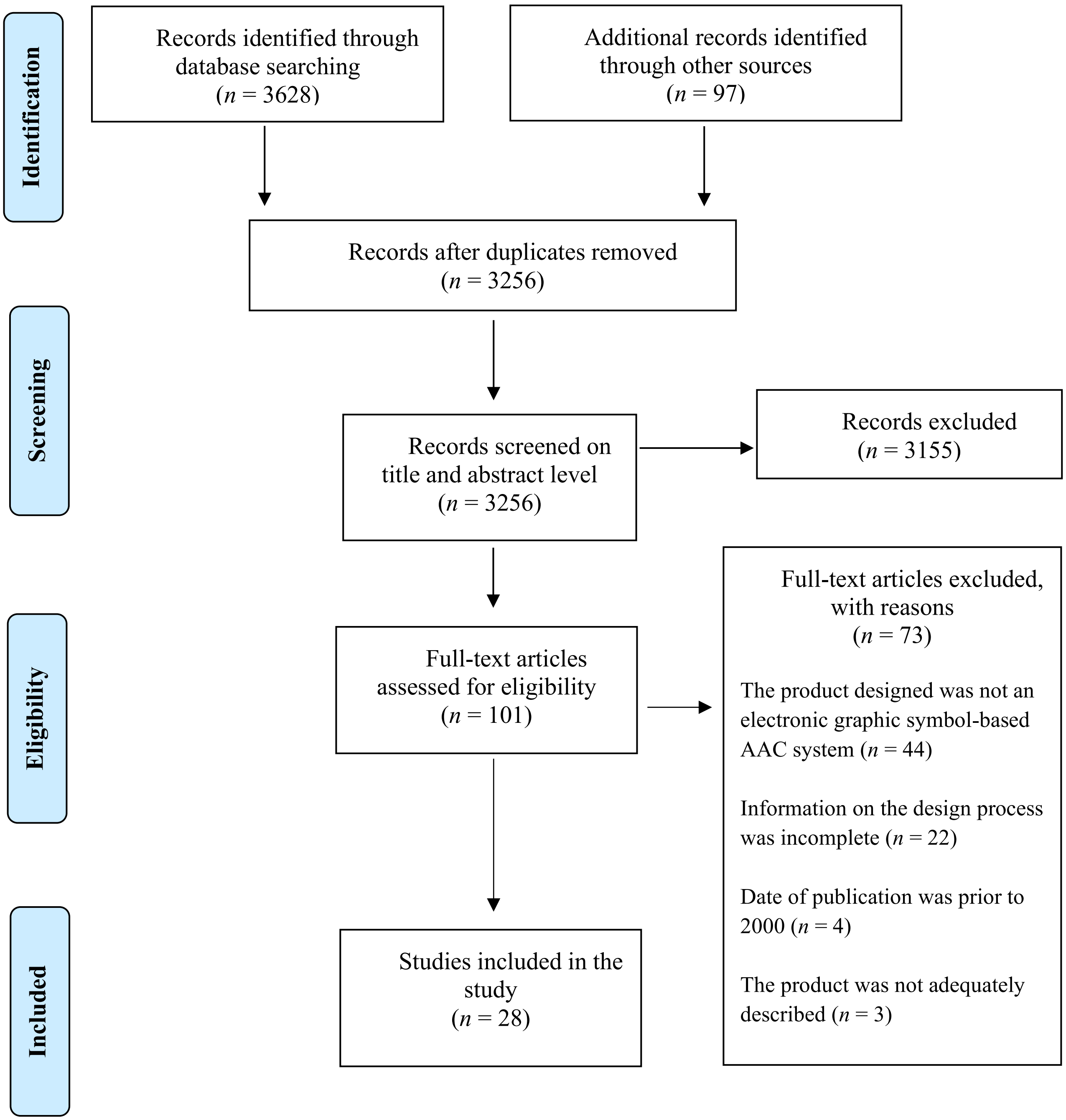

Figure 1. PRISMA flow diagram of the study identification and selection process.

Appendix A

Table A1

Overview of the Characteristics of the 28 Studies Included within this Review

Authors	**Aim**	**Author disciplinary/ institutional affiliation**	**Country, World Bank classification**	**Name and/or description of product designed**	**Language**
Al Arifi et al. [68]	To describe the development and evaluation of an iOS AAC application for Arabic-speaking individuals with speech impairments.	Computer and Information Sciences	Saudi Arabia (HI)	Touch-to-Speak, a prototype of an iOS-based AAC application for an iPad.	Arabic
Allen [23]	To address the design and development of a wearable communication aid for people who are illiterate and cannot speak.	Faculty of Art and Design	United Kingdom (HI)	Portland Communication Aid (PCA), a dedicated communication aid prototype consisting of a book with icon keyboard, a waist pack with hardware and a mobile speaker unit.	English
An et al. [97]	To describe the development and evaluation of an AAC mobile app (Yuudee) in the Chinese language.	School of Life Sciences of Beijing Normal University, National Institute of Biological Sciences, AppChina, Beijing Stars and Rain Education Institute, Academy of Arts and Design of Tsinghua University, Inway Design, G-Wearables, Inc., Center for Bioinformatics	Mainland China (UMI)	Yuudee, an iOS- and Android-based AAC application.	Chinese
Babic et al. [98]	"To propose software development process for AAC applications, that follows specific principles to successfully implement all	Faculty of Electrical Engineering and Computing	Croatia (HI)	Komunikator+, an iOS- and Android-based AAC application.	Croatian

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Authors	Aim	Author disciplinary/ institutional affiliation	Country, World Bank classification	Name and/or description of product designed	Language
	functional and accessible features that applications should contain in order to be accessible and highly usable" (p. 2).				
Bhattacharya and Basu [66]	To develop and present a novel user-computer interaction model that uses Bengali and Hindi as the languages of instruction to convert icon sequences into grammatically correct phrases and sentences.	Department of Computer Science and Engineering	India (LMI)	Sanyog, an icon-based communication aid built for a Desktop PC with a 17-inch monitor.	Hindi and Bengali
Boyd-Graber et al. [99]	To describe the design and preliminary evaluation of a hybrid desktop-handheld system developed to support individuals with aphasia.	Computer Science	Montréal, Québec, Canada (HI)	Hybrid ESI (Enhanced with Sound and Images) Planner II-LgLite system, a high-fidelity prototype that "allows its users to develop speech communication through images and sound on a desktop computer and download this speech to a mobile device that can then support communication outside the home." (p. 151)	English
Cheung et al. [68]	To present a mobile AAC application (MAAC) for disabled people.	Department of Computing	Hong Kong Special Administrative Region (HI)	Mobile augmentative and alternative communication application (MAAC), an iOS- and Android-based AAC application for smartphones and/or tablets.	Chinese
da Silva et al. [79]	To develop an AAC tool that adapts to the specific motor difficulty characteristics of persons with CP.	Centre for Technological Research and Federal Institute of Education, Science and Technology	Brazil (UMI)	AACVOX, an iOS- and Android-based AAC application.	Not specified

Electronic graphic symbol-based AAC: Part 1

Authors	Aim	Author disciplinary/ institutional affiliation	Country, World Bank classification	Name and/or description of product designed	Language
de Faria Borges et al. [100]	To report the results of an action research conducted to design a communication device to help a non-verbal child develop language skills.	Electrical Engineering	Brazil (UMI)	A high-fidelity prototype of an AAC application designed for a computational device such as a tablet.	Portuguese
Daemen et al. [74]	To describe the design and evaluation of a storytelling application for individuals with expressive aphasia.	User System Interaction of Technische Universiteit Eindhoven, Industrial Design of Technische Universiteit Eindhoven, Philips Research	Netherlands (HI)	A prototype storytelling AAC application developed in PC Macromedia Director and loaded onto a tablet PC with a webcam attached.	English
de Oliveira et al. [75]	To discuss the development of a free GS-based AAC application, called VoxLaps, for Brazilian Portuguese speakers	Computer science, Development Centre for Assistive Technology and Accessibility	Brazil (UMI)	VoxLaps, an AAC application designed for any Android system.	Portuguese
Di Mascio et al. [86]	To develop a personalisable ASD-oriented high-tech aided AAC prototype.	Department of Information, Engineering, Computer Science and Mathematics; Department of Applied Clinical Sciences & Biotechnology; Centre for Autism	Italy (HI)	A prototype of an AAC application for persons with ASD designed for a tablet and/or smartphone.	Not specified.
Hayes et al. [101]	To present the results and interventions associated with prototype systems namely: Mocotos, a mobile visual augmentative communication aid and vSked, a multi-device interactive visual schedule system that can address design challenges.	Department of Informatics (School of Information and Computer Sciences)	USA (HI)	Mocotos, a prototype of a mobile visual AAC aid, consisting of software loaded onto a Nokia tablet.	English

Electronic graphic symbol-based AAC: Part 1

Authors	**Aim**	**Author disciplinary/ institutional affiliation**	**Country, World Bank classification**	**Name and/or description of product designed**	**Language**
Hervás et al. [76]	To present the design and evaluation of an AAC system's prediction mechanisms aimed for the composition of messages using pictograms.	Faculty of Informatics; Higher Polytechnic School; the Institute of Knowledge Technology	Spain (HI)	PictoEditor, an AAC application designer for a tablet.	Spanish
Hill [65]	To present principles of design based on evidence-based practice (EBP) and language activity monitoring (LAM) using the evaluation of a Mandarin language software application as an example of how the steps of EBP and LAM data were applied during the initial research tasks.	Department of Communication Science and Disorders	USA (HI)	A prototype of a Mandarin Language System designed for a (presumably dedicated) SGD.	Mandarin
Hine et al. [102]	To address challenges of portability and mobility in AAC focusing on migrating a desktop multimedia AAC application onto a palmtop personal data assistant (PDA).	Division of Applied Computing	Scotland (HI)	A multi-media AAC application loaded onto PDAs.	English
Hirotomi [71]	To examine the change in the behaviours and attitudes of children with CCN and their communication peers when using the Stalk2 mobile application.	Science and Engineering	Japan (HI)	Stalk2, an AAC application designed for an Android OS system.	Japanese
Jafri et al. [87]	To develop a low-cost, gaze interaction-based Arabic language application to assist pre-literate and early literate individuals with severe speech and motor impairments [SSMI] whose primary language is Arabic to communicate with people in their vicinity (p. 281).	Department of Information Technology	Saudi Arabia (HI)	Esmaany ("Listen to Me"), a low-cost, gaze interaction-based Arabic language application designed for Microsoft Windows PCs.	Arabic
Karita [69]	To develop an application that displays voice output communication aid [VOCA] interfaces according to locations and time of the user both outdoors and indoors.	Faculty of Education	Japan (HI)	Friendly VOCA, an AAC application that is compatible with iOS devices.	Japanese
Lubas et al. [103]	To provide an example of the user-centred (by proxy) design process used to develop an AAC application for children with	Department of Social Work; College of Health Sciences; Virginia Modeling	USA (HI)	I Click I Talk, an AAC application designed for Apple and Android devices.	English

Electronic graphic symbol-based AAC: Part 1

Authors	Aim	Author disciplinary/ institutional affiliation	Country, World Bank classification	Name and/or description of product designed	Language
	communication impairments as a result of ASD.	Analysis and Simulation Center; Virginia Deparrment of Education; Tookty®LLC			
Mahmud et al. [72]	To describe the design of CoCreation, an assistive tool that can help people with aphasia to express daily experiences by utilising digital photographs.	Design Conceptualisation and Communication Group, Faculty of Industrial Design Engineering; Department of Industrial Design	The Netherlands (HI)	CoCreation, a prototype of an AAC application intended for a PDA or a tablet.	Dutch
Martin et al. [77]	To describe the design, development, and evaluation of an application to help people with ASD express themselves through the creation of stories and comics.	Computer Engineering; Alenta College, Institute of Psycho-Pediatrics	Spain (HI)	Today I Tell, a prototype of an AAC application designed for a smartphone and/or tablet.	Spanish
Mendes and Correia [104]	To develop an AAC application for smartphone and tablet (Vox4all®) in a sustainable way, starting with a simple communication system and adding features based on research, experience and observation of real situations.	Imagina (manufacturer in Portugal)	Portugal (HI)	Vox4all®, an AAC application designed for a smartphone and/or tablet.	Not specified
Rodríguez-Sedano et al. [70]	To discuss the use of a new visual language, known as VILA (VIsual LAnguage) and present a first evaluation of a software prototype.	Robotics Group, Department of Mechanical, Computer Science and Aerospace Engineering	Spain (HI)	An AAC software prototype, Visual Language (VILA).	English and Spanish
Saturno et al. [105]	To mitigate communication problems of children and adolescents with CP through the development of an AAC tool.	Applied Computing Department; Catarinense Foundation for Special Ecducation	Brazil (UMI)	A prototype of an AAC computer-based solution.	Portuguese

Electronic graphic symbol-based AAC: Part 1

Authors	Aim	Author disciplinary/ institutional affiliation	Country, World Bank classification	Name and/or description of product designed	Language
Stančić et al. [106]	To present the development of an iPad-based AAC application ('Communicator').	Faculty of Education and Rehabilitation Sciences; Faculty of Electrical Engineering and Computing; Faculty of Humanities and Social Sciences; Faculty of Graphic Arts	Croatia (HI)	Communicator, an AAC application designed for an iPad.	Not specified
van de Sandt-Koenderman et al. [73]	To develop a portable computerised communication aid for aphasic people to support communication in everyday life.	Rijndam Rehabilitation Centre; Department of Rehabilitation Medicine; Speech and Language Therapy Research Unit	UK, Portugal, Netherlands (HI)	A prototype of a portable communication aid for dysphasic people (PCAD), consisting of software (Touchspeak®) run on the client's palmtop computer and the therapist's PC.	Not specified
William et al. [78]	To investigate the design of vocabulary prompts on a head-worn display for individuals with aphasia.	College of Information Studies (University of Maryland), School of Information Studies (McGill University), Snyder Centre for Aphasia Life Enhancement	USA (HI)	A head-worn glass AAC (GLAAC) prototype which is an Android-based AAC application for Google Glass.	Not specified

Note. HI = high income, UMI = upper middle income, LMI = lower middle income