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

by

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The author declares that she has observed the ethical standards required in terms of the University of Pretoria's Code of ethics for researchers and the Policy guidelines for responsible research.

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ABSTRACT

Background: Electronic graphic symbol-based augmentative and alternative communication (AAC) systems can facilitate participation and engagement in various life activities by providing individuals with complex communication needs access to alternative forms of communication. However, designing such systems can be a daunting and complex task. Not only do the designers have to keep up with the ever-growing advances in technology, but they must also try to match the varying features available for graphic symbol-based AAC systems with the heterogenous group of individuals for whom these systems are designed, the tasks that the system should help the users to accomplish, and the context of use. Moreover, the interchangeable use of Human Centred Design (HCD) terminology, and the eclectic approach to designing assistive technology, makes identifying and using a particular design approach and method to design graphic symbol-based AAC systems difficult. Therefore, the aim of this study is to map the literature reporting on the design studies of such systems and to provide an overview of documented approaches, principles, input, outcomes, and methods used in the design of graphic symbol-based AAC systems to facilitate an understanding of the current state of the field.

Methods: A scoping review was conducted whereby a comprehensive and multifaceted search of 11 databases found 28 studies that met the predetermined selection criteria. Descriptive data was extracted independently by two persons, using a predetermined data extraction table. Data was extracted relating to seven areas of interest, namely (a) the characteristics of the design studies, (b) the features of the systems designed, (c) the design approaches and principles used, (d) the input obtained before and during the design process, (e) persons involved, (f) product evaluations and outcomes, and (g) the limitations and recommendations provided within these studies. Data was analysed using descriptive statistics (predominantly frequency counts) and summarised in text and using graphs.

Results: The findings indicated that most of the studies reported on the design of graphic symbol-based AAC applications or software to be loaded onto mobile technology devices, which is in accordance with the mobile technology revolution. HCD approaches were rarely and inconsistently reported, and few studies followed all six HCD principles. A positive outcome was the inclusion of users/stakeholders within the design process; however, due to varying constraints within the design process, the type of and extent to which they were included varied.

The methods used to gain information and evaluate the product are consistent with the literature. Few of the systems designed are currently available to the public and ongoing development is required.

Conclusions: There is a need for designers to be more transparent about the type of design approach used to guide the system design and also to clearly report on design approaches and processes used. Research is required to explore further the development of graphic symbol-based AAC systems and to obtain a better understanding of the decision-making throughout the design process.

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ARASAAC	The Aragonese centre of augmentative and alternative communication
ASD	Autism spectrum disorder
AT	Assistive Technology
AAC	Augmentative and Alternative Communication
CAT	Comprehensive Assistive Technology
CCN	Complex communication needs
CP	Cerebral palsy
GS	Graphic symbol(s)
HAAT	Human Activity Assistive Technology
HCD	Human Centred Design
ISO	International Organization for Standardization
JIT	Just-in-time
OT	Occupational Therapist
PDA	Personal data assistant
PCS	Picture communication symbols
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews
RSS	Really Simple Syndication
SGD	Speech generating device
SLT	Speech-Language Therapist
SUS	System usability scale
UCD	User-centred design
VSD	Visual scene display

1 INTRODUCTION

1.1 Problem statement

Access to communication can afford people the chance to actively immerse themselves within a society and their community (Dada, Kathard, et al., 2017). Through expressing needs and opinions, exchanging personal thoughts and sharing knowledge and insights, an individual can build relationships, socialise amongst peers, learn, and work within various contexts (Beukelman et al., 2016; Dada, Kathard, et al., 2017). Naturally, persons with complex communication needs (CCN), without access to a functional method of expressing themselves, are at risk of limited participation within multiple activities relating to education, employment, and family and community activities (Light et al., 2019).

If designed appropriately, augmentative and alternative communication (AAC) systems and strategies such as a graphic symbol-based (GS-based) AAC system can provide access to an alternative form of communication, whereby individuals with CCN can gain independence in their participation and engagement within their community (McNaughton et al., 2019). Such systems can also afford individuals with CCN the opportunity to build social connections within multiple contexts (McNaughton et al., 2019; Smith, 2018). In addition, if implemented early, GS-based AAC systems can also positively influence language development and learning amongst children (O'Neill & Wilkinson, 2019).

Persons with CCN typically require AAC services throughout their lifetime, and thus the implication for the design of AAC systems is that the system needs to grow with the person (O'Neill & Wilkinson, 2019; Weed et al., 2011). Moreover, because communication is never a solitary activity, the effectiveness of an AAC system may also be influenced by the communication partner (Light, Wilkinson, et al., 2019; Von Tetzchner et al., 1996). It is therefore vital for AAC researchers and designers to continuously develop GS-based AAC systems in a manner that can offer an individual access to an extensive, age-appropriate vocabulary (to improve expressive language and language development), as well as develop a system that can be used and understood by multiple communication partners within various interactions and activities, to further facilitate participation in multiple settings (McNaughton & Light, 2013).

Section 1: Introduction

To ensure the successful implementation, use, and acceptance of a GS-based AAC system by persons with CCN, the AAC researcher and designer must have knowledge of the latest AAC system research, as well as a sound understanding of persons with CCN and their communicating partners, the task that they want to accomplish, and the environment in which this task is to be accomplished, in order to ensure that the system's design features are well suited to these aspects (Allen, 2005; Cook et al., 2019; Reichle & Drager, 2010).

Unfortunately, AAC service providers, including designers, face an enormous challenge in AAC service provision and AAC design due to the heterogenous group of individuals they serve (Dada, Murphy, et al., 2017; Soto & Yu, 2014). Due to an individual's unique experiences, capabilities, needs, and preferences, the AAC design requirements will vary across this population (Webb et al., 2019). For example, a child who is preliterate will require different system features (e.g., graphic symbols embedded on an AAC system), as opposed to an adult whose literacy may be intact, and therefore may only require an alphabet/text-based AAC system (Light & Drager, 2002; Thistle & Wilkinson, 2015; Webb et al., 2019).

In addition, the diversity of the group of individuals who require AAC systems is not only a result of the wide variety of their speech-language abilities, motor functioning, sensory-perceptual skills or cognitive functioning, but is also due to differences in their age, gender, social, financial, cultural, and linguistic background (Light & Drager, 2002; Ogletree et al., 2018; Webb et al., 2019). Consequently, designing a system suitable for the specific needs of an individual that can be easily integrated into all aspects of an individual's life may be challenging.

Although there may not be uniform answers to the mentioned challenges due to the heterogeneity of the population for whom such systems are designed (Dell'Era & Landoni, 2014), some form of guideline could prove beneficial for designers. As a starting point, the design approach and principles, methods, input obtained, and concomitant outcomes in designing GS-based AAC systems that have been documented in the literature can be summarised and described systematically in order to understand the current state of the field.

1.2 Terminology

Here follows a list of commonly used terms accompanied by definitions adopted for this study.

1.2.1 Assistive technology

Assistive Technology (AT) can be described as "any item, piece of equipment or product system, whether acquired commercially off the shelf, modified, or customised, that is used to increase, maintain or improve the functional capabilities of a [person] with a disability" (Individuals with Disabilities Education Act, 2004, Section 602, 1A).

1.2.2 Complex communication needs

Complex communication needs (CCN) refers to an impairment in speech and/or language which may include spoken and written forms of communication that results in the inability to meet communication needs through natural speech alone (Beukelman & Light, 2020).

1.2.3 Dedicated device

Dedicated devices are aided AAC systems that are specifically designed to support communication for persons with CCN and thus cannot be used for other functions such as sending emails or making phone calls (McNaughton & Light, 2013). An example of a dedicated AAC device is the SuperTalker FT[1].

1.2.4 Electronic GS-based AAC system

In this review, an electronic GS-based AAC system refers to any AAC system or AAC application that requires a source of electricity (e.g., battery) to function, and which consists of GS representations that are organised and displayed on an interface whereby an individual using the system can access these GS representations in some way, for example, by touching or selecting symbols using switches or a cursor (Beukelman & Light, 2020). Such a system typically also includes voice or speech output, either in the form of synthetic speech or recorded (digital) speech that is used in conjunction with the GS representations (Beukelman & Light, 2020).

[1] SuperTalker FT is a product of AbleNet, Inc, Roseville, MN, USA, https://www.ablenetinc.com/supertalker-ft/.

1.2.5 Graphic symbols

Graphic symbols are two-dimensional visual displays that represent a referent to convey a particular concept or meaning (Beukelman & Light, 2020; Huang & Lin, 2019; Webb et al., 2019). Examples of such graphic representations include photographs/pictures, icons, line drawings, and images (Beukelman & Light, 2020).

1.2.6 Non-dedicated device

A non-dedicated AAC device encompasses AAC software or an application on any mainstream hardware device, such as a tablet or iPad (McNaughton & Light, 2013; York & Fabrikant, 2011). An example of an application that can be downloaded on a mainstream device is GoTalk NOW[2].

1.2.7 Prototype

A prototype is a type of sketch/2D/3D model that represents the product that is intended to be designed and/or manufactured (Buchenau & Suri, 2000). Individuals and/or relevant stakeholders can use such prototypes and provide suggestions and feedback regarding the effectiveness of the design, which is also known as experience prototyping (Black et al., 2012; Buchenau & Suri, 2000).

1.2.8 Stakeholders

In this review, stakeholders refer to persons who are actively involved in the use of an AAC system together with the person with CCN for whom the system is intended (Uthoff et al., 2021). These individuals may include caregivers, family members, peers, educators, and healthcare providers such as a speech-language therapist (SLT), occupational therapist (OT), physiotherapist, and psychologist (Beukelman & Light, 2020; Uthoff et al., 2021).

1.2.9 Usability

Usability is defined in the International Organization for Standardization (ISO) 9241-210: 2019 standard (cited by Tosi, 2020) as an overarching construct that encompasses the extent to

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[2] GoTalk NOW application is a product of Attainment Company, Inc, Verona, WI, USA, https://www.attainmentcompany.com/gotalk-now.

which a system or product meets the needs of the individual and can be used to achieve their specific goals with effectiveness, efficiency and satisfaction.

1.2.10 User

The word ‘user’ is commonly documented within AT literature and refers to the specific individual/s for whom the product is designed (Dell’Era & Landoni, 2014). In this thesis, it would refer to the person with CCN who requires AAC.

2 LITERATURE REVIEW

To provide some background on the study, the literature on the following topics will be briefly reviewed: (a) assistive technology and AAC system design; (b) challenges with assistive technology and AAC design, (c) human centred design approaches and principles, (d) the input required to design a GS-based AAC system, and (e) methods used to obtain input.

2.1 Assistive technology and AAC system design

Assistive technology (AT) devices, such as a wheelchair or an aided AAC system, are aimed at promoting an individual's engagement in learning activities, as well as enabling them to perform everyday activities that would have previously proven difficult (Dunst et al., 2013; Magnier et al., 2012). Aided AAC systems include non-electronic solutions (e.g., communication boards), and electronic solutions (e.g., dedicated and non-dedicated devices) that specifically aim to improve communication for persons with CCN (Beukelman & Light, 2020; Waller, 2019).

For persons who are not (yet) literate, graphic symbols can be used to enhance understanding (e.g., when presented on a schedule), but when incorporated into an electronic or non-electronic AAC system, their purpose typically is to represent language and provide an alternative means of expression for persons with CCN (Judge et al., 2019). Also, when such systems are provided to young children, they are typically expected to scaffold expressive language development (Waller, 2019).

At a minimum, an electronic GS-based AAC system typically consists of (a) graphic symbols that represent a referent to encode concepts, words or morphemes, sentences/phrases, or may represent a specific semantic field that is then narrowed down by selecting subsequent symbols (Baker & Chang, 2006; Beukelman & Light, 2020; Huang & Lin, 2019; Tenny, 2016; Webb et al., 2019); (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 (Beukelman & Light, 2020; Gosnell et al., 2011); and (c) voice or speech output, either in the form of synthetic speech or recorded (digital) speech (Gosnell et al., 2011; Pullin et al., 2017). Systems with the latter capability are therefore also referred to as speech generating devices (SGDs) (An et al., 2017). Ultimately, these features are aimed at making it possible for faster, clearer and more independent communication and interaction with various communication partners in the individual's environment (Beukelman & Light, 2020).

Non-dedicated AAC devices in particular have become more accessible and affordable to many individuals who use AAC (McNaughton & Light, 2013; Ogletree et al., 2018). These multipurpose devices offer a wide range of additional features such as internet access, texting, and social media, which allows for a wider range of communication opportunities (McNaughton & Light, 2013). In addition, advances in computing have made a number of additional AAC system functionalities and features possible, such as animated symbols, text prediction and pop-up windows with grammar and morphology options (Gosnell et al., 2011; McNaughton & Light, 2013; Waller, 2019). In many ways, these have revolutionised the manner in which such systems function, and what they offer to the person who needs them (McNaughton & Light, 2013). Moreover, with regards to the physical look and feel of such systems, the use of mainstream technology (such as mobile phones) has also increased the aesthetic appeal of the device, thereby reducing stigmatisation by providing a more socially accepted means of communication (Boster & McCarthy, 2018; Dada, Murphy, et al., 2017; Ogletree et al., 2018).

Despite numerous technological advances, AT and AAC system designers still face many challenges in the design process. A high rate of AAC system abandonment suggests that the products and systems provided to persons with CCN and their communication partners often do not seem to meet the needs of the individual and their stakeholders (Dunst et al., 2013; Moorcroft et al., 2019; Waller, 2019).

2.2 Challenges with AT and AAC system design

A fundamental challenge of AT/AAC system design is that systems are typically designed for a relatively small, albeit diverse, market (Choi, 2011). In order to enhance the usability and appeal of such systems, designers are tasked with balancing various tensions, such as matching the varying features available for GS-based AAC systems with the heterogenous group of individuals for whom these systems are designed (Light et al., 2007; Waller, 2019). For example, designers will need to consider reducing the cognitive demands of a system (e.g., the number of GS representations on a display), while still ensuring individuals have access to the appropriate language coverage that will facilitate greater language growth and conversation (Tenny, 2016; Thistle & Wilkinson, 2013).

It is with this perspective that Ogletree et al. (2018) encouraged technology and software designers to follow a universal design ('design for all') approach when designing features for non-dedicated AAC systems which aim to accommodate a wide range of individuals with physical and/or cognitive disabilities and communication difficulties. These mainstream devices are more commonly available, and thus more cost effective compared to devices that are specifically designed as AAC systems and therefore intended for a smaller, homogenous group of individuals (i.e., dedicated AAC devices) (Dada, Murphy, et al., 2017; McNaughton & Light, 2013; Waller, 2019). However, the universal design approach of Ogletree et al. (2018) may not always suit or match the needs of persons with physical disabilities and CCN, as the non-dedicated systems require fine motor movement and cognitive and sensory-perceptual skills (McNaughton & Light, 2013). Consequently, this approach runs the risk of omitting the needs of a specific group, rendering the device ineffective, and often leading to the abandonment of such AAC products (Dunst et al., 2013; Tao et al., 2020; Waller, 2019).

Financial constraints and a lack of funding to support research and AAC technology development frequently result in designers reiterating or reproducing existing (or older) communication board features which were designed as early as the 1980s (Light et al., 2019). This means that the features included within such AAC systems still commonly reflect American or European language, perspectives and cultural norms (Light & Drager, 2002). Therefore, GS-based AAC systems are typically structured around the English language and do not easily accommodate the use of additional languages (Light & Drager, 2002; Tönsing et al., 2020). This is a significant design limitation and challenge, as failing to design systems that give access to multiple languages can make individuals from multilingual backgrounds feel isolated within their community, as well as limit their participation in multiple interactions and contexts (Light & Drager, 2002; Tönsing et al., 2020). For a diverse country such as South Africa, which represents multiple cultures and languages, it is vital that GS-based AAC systems are culturally and linguistically appropriate (Tönsing et al., 2019). Unfortunately, current designs often do not reflect the latest research evidence and are not developmentally appropriate or context specific (Light et al., 2019).

Moreover, the lack of many designers' knowledge and prior exposure to a specific population's needs and capablities is a common challenge to designing effective and useful products for persons with CCN (Boster & McCarthy, 2018; Hwang & Park, 2018). Consequently, there is often a mismatch between the AAC design features and the individual needs of the targeted population group (York & Fabrikant, 2011).

Indeed, a common critique of AAC system design and AT design is that the manufacturer (or designer) designs these systems independent to the population for whom they are intended (Boster & McCarthy, 2018; Light & Drager, 2002; Ogletree et al., 2018; Sanders et al., 2006). Arguably, this is due to AAC innovations being technology driven (Ogletree et al., 2018). Thus, the emphasis is often on the application and construction of the technology, rather than on the psychological and sociological impact of the design, as well as the needs, preferences and contextual background of a specific population (Allen, 2005). Furthermore, the abilities, needs and expectations of the individual's stakeholders (i.e., caregivers, peers and service providers) are often poorly conceptualised in AAC intervention and AAC system design (Light, McNaughton et al., 2019; Von Tetzchner & Stadskleiv, 2016). The inability to meet the specific needs of the individual and their stakeholders often leads to the abandonment of such AT products (Dunst et al., 2013; Tao et al., 2020).

Researchers have advocated for an approach that incorporates the individual's desires, preferences and abilities (skills) within the design of AAC systems and interface features, which also includes features that allow for customisation to ensure the system is easily adaptable or personalised to accommodate the individual's needs (Allen, 2005; Boster & McCarthy, 2018; Cook & Polgar, 2015). In an effort to reduce the abandonment of AT and to display an adequate, holistic understanding of the individual, the involvement of persons with disabilities in the design and development of AT devices through Human Centred Design (HCD) approaches has been suggested as a crucial approach to AT design (Sanders & Stappers, 2008; Waller et al., 2005).

2.3 Human Centred Design

Human Centred Design (HCD) has influenced AT design practice since the 1990s and has shifted the focus from the 'user' as the subject, previously addressed through a user-centred design (UCD) approach, to actively involving individuals within the design process (Brischetto, 2020; Sanders & Stappers, 2008). The main premise of the HCD framework is that HCD practitioners (typically the technology/software developer and designer) learn from, and cooperate with, individuals and/or relevant stakeholders for whom the system or product is developed (Hwang & Park, 2018; Steen, 2011). The HCD framework provides guidance in terms of a design process, design approaches which can guide design methods, and HCD principles that assist in the inclusion of users and their stakeholders, as well as the evaluation of the design methods used within the design of a product (Brischetto, 2020).

An HCD process typically includes four iterative stages as illustrated in Tosi (2020), based on the ISO 9241-210: 2019 standard. The first two stages entail information gathering and encapsulate the designers' need to understand and specify the context of use, as well as specify the requirements of the target population (Tosi, 2020). The third stage includes producing and assessing design solutions which often includes prototyping (Tosi, 2020). The fourth stage, hereafter referred to as the 'end product evaluation', is the evaluation of the product against the design requirements set out earlier in the process (Tosi, 2020). It must be acknowledged that HCD practitioners are often required to adjust or reiterate a design process to compensate for many challenges and tensions designers face when creating products, and thus the design process cannot be linear (Moggridge, 2017; Steen, 2011).

Furthermore, engaging stakeholders within the design process requires much thought and preparation (Choi, 2011). Designers ought to ask questions and determine how the stakeholders will be engaged and/or recruited, at which part of the process they will be involved, what role they will play, and how they will be compensated for their time (Choi, 2011). There are several approaches that fall under the overarching HCD framework (e.g., ethnographic design, co-design, lead-user approach, and participatory design) that can be used to help facilitate the individual and their stakeholder's involvement and contributions within the AT design decision-making process (Steen, 2011).

While these design approaches follow a similar design process, each of their key focal points differ (Sanders & Stappers, 2008). For example: a participatory design promotes the active involvement of individuals throughout the design process and as such, stakeholders are treated as experts who play a role in the exploration and creation of alternative solutions for new products throughout the design process (Spinuzzi, 2005; Steen, 2011). In contrast, an ethnographic design includes individuals as passive participators where the designer's goal is to better understand the target population's needs through observations of these individuals within naturally occurring activities (Steen, 2011).

This leads to the two different roles a stakeholder can play within the design process. In an informative role, a designer consults with stakeholders to gain more information regarding their needs, their task and their context, as well as to garner more information on the usefulness of a product (Damodaran, 1996; Dell'Era & Landoni, 2014). Alternatively, a stakeholder can be used in a participative (collaborative) manner, whereby they are seen as co-creators and may influence decisions relating to the design of the intended product (Damodaran, 1996; Dell'Era & Landoni, 2014). The latter is reportedly preferable but not always possible due to various limitations and constraints such as time, costs, ethical considerations, and the diversity and heterogeneity of people who use AT (Marti & Bannon, 2009; Waller et al., 2005). The aforementioned limitations and constraints may make following a single approach difficult (Marti & Bannon, 2009; Waller et al., 2005). This may result in designers using an eclectic approach to design (Steen, 2011).

Although there are different approaches within HCD, they all share the same set of design principles as set out below by the ISO 9241-210:2019 standard, as cited in Shekhovtsova et al. (2020, p. 78):

1. The design is based on a clear understanding of the individual, their tasks, and contexts.
2. The individual and/or their stakeholders are involved in the design and development process.
3. The design is driven and defined based on the user group's feedback.
4. The process is iterative.
5. The user group's experience is addressed holistically within the design.
6. The team is multidisciplinary, which will include various skills and perspectives.

These six principles can be used to evaluate the design methods used to design any AT product, including the design of GS-based AAC systems (Shekhovtsova et al., 2020). The principles describe the type of information or input needed to inform the design process (Principle 1), the design process itself, including evaluation/feedback (Principles 2-5), and the design team composition (Principle 6) that underlie HCD (Shekhovtsova et al., 2020).

2.4 Input required to design a GS-based AAC system

According to Dubberly (2004), designing is a process, and is exeplified by the archetypal process model of input—process—output. Input is obtained before commencing with the design process but also during the iterative process stage of the design. Once a product has been designed, an appropriate evaluation of the product is necessary to identify its overall success (Tao et al., 2020).

Designers are urged to look for novel ways of improving and developing past practices in the design of a product while still acknowledging, and potentially making use of, those practices that have come before (Steen, 2011). In order to do so, designers may rely on a variety of input from several sources to gain information that can inform the design process (Choi, 2011), alongside selecting an appropriate HCD approach that will suit the specific population and product requirements (Steen, 2011).

2.4.1 Input based on various components

The usability of a system and user performance is a function of the interplay between the device (assistive technology), the person using the device (human), the task to be accomplished (activity), and the environment in which it is to be accomplished (context) (Cook et al., 2019). This is highlighted in the first principle of HCD, where designers require a good understanding of the individual, their tasks, and their contexts in order to design products that are useful (Shekhovtsova et al., 2020). Identifying and understanding these four components is in accordance with the Human Activity Assistive Technology (HAAT) model (Cook et al., 2019), which is based on Bailey's (1989) human performance framework, and was conceptualised to describe how a person utilises any form of AT in order to perform a task. In addition, the Comprehensive Assistive Technology (CAT) model (Hersh & Johnson, 2008) further expanded the HAAT model, adding additional subcategories and descriptions to each of the four HAAT components. Van Niekerk and Tönsing (2015) added a fifth component, namely a communication partner, to model the use of a GS-based AAC system for face-to-face interactions.

While it is beyond the scope of this literature review to summarise all current knowledge on these five aspects in relation to persons in need of GS-based AAC systems, a few key thoughts will be highlighted in the sections following. Furthermore, it must be acknowledged that a separation of the components of a systemic model is to some extent artificial, and that actual performance of a system depends on the synergy of all components.

2.4.1.1 Person (‘user’) and their communicating partner(s)

Persons in need of a GS-based AAC system are a heterogenous group, and can be described by a number of different factors, such as their diagnosis, personal information (including aspects such as age, gender, home language, and cultural identity), personality and preferences, psychosocial factors (e.g., motivation, attitude, and confidence), body functions and structures, and impairments/disabilities, as well as skills, competencies and abilities (Light & McNaughton, 2014; Raghavendra et al., 2007). The only common denominators of this group are CCN and presumably limited literacy, as literate individuals often use text-based AAC systems (Beukelman & Light, 2020).

The significance of having knowledge of the individual/group of individuals for whom the GS-based system is designed can be described as twofold. First, designers need to ensure that the individual can use the device. This means that the user has the physical, cognitive, linguistic, social and strategic skill to operate the device within a given communication situation (Light & McNaughton, 2014). Second, they need to ensure that the user wants to use the device (Weed et al., 2011). The latter is dependent on several factors, including (but not limited to) the compatibility of the device with the user's preferences, personality and personal characteristics (Light & Drager, 2002). For example, the vocabulary included and the voice used on an SGD should be age- and gender-appropriate.

Moreover, communication is a collaborative task which always requires at least two people (von Tetzchner & Stadskleiv, 2016). Consequently, successful communication relies on both the skills of the individual and their communicating partner (stakeholder) during conversation (Teachman & Gibson, 2014; von Tetzchner & Stadskleiv, 2016). A communicating partner's skill set (that is, their ability to use and understand the AAC system), their ability to scaffold language, and their level of acceptance of such alternative forms of communication can influence the success of communication and interaction with individuals who use GS-based AAC systems (Van Niekerk & Tönsing, 2015). Therefore, it is vital that designers keep in mind who the communicating partners/stakeholders are and how the system can be designed to ensure it is easy to use and/or understand by all communicating partners (Valencia et al., 2020).

2.4.1.2 Task

GS-based AAC systems are typically designed to assist the user to express themselves in various face-to-face (and sometimes also remote) communication situations (Light & McNaughton, 2014). Beukelman and Light (2020), based on Light (1988), identified four different social purposes of communication interactions, namely expression of needs and wants, information transfer, social closeness, and social etiquette. Depending on the purpose of the interaction, its length, content, predictability, scope and rate may vary (Beukelman & Light, 2020). The degree to which there is tolerance for breakdown and the degree to which the communicator is expected to be independent and convey his/her own ideas may also differ (Beukelman & Light, 2020). Designers should thus be aware of different purposes of interactions and the associated interaction parameters, to ensure that a GS-based system can meet them as best possible.

GS-based AAC systems may also serve the purpose of supporting the expressive language development of children, including semantic, morpho-syntactic, and pragmatic development (Blockberger & Johnston, 2003; O'Neill & Wilkinson, 2019; Weed et al., 2011). Consequently, it is vital to ensure that the system can develop/evolve with the user to support increasingly complex language and literacy skills.

2.4.1.3 Context

Contextual factors have a significant influence on the individual's ability to perform a task within multiple environments (Cook et al., 2019). Not only does the portability of the system need to be considered when moving between contexts (Dada, Kathard, et al., 2017; Van Niekerk & Tönsing, 2015), but various parameters of the physical environment within which the device is to be used may also need to be considered (Van Niekerk & Tönsing, 2015). For example, designers should consider how the position of the device in relation to the individual and their communicating partner can accommodate face-to-face interaction and facilitate eye contact within a given communication setting/environment (Ibrahim et al., 2018). In addition, other considerations should include aspects such as lighting and noise levels; for example, whether or not the partner(s) can see the AAC device or hear the voice output (Van Niekerk & Tönsing, 2015).

Despite the implementation of polices and frameworks that promote an inclusive society, the lack of resources, limited access to healthcare and education and high unemployment rates are still prominent for persons with disability (Dada, Kathard, et al., 2017; De Sas Kropiwnicki et al., 2014). The lack of financial resources or support may prevent individuals from acquiring high-technology devices (Van Niekerk & Tönsing, 2015). As such, designers must be mindful of the societal macro-context and influencing factors such as general acceptance of persons with disability, technology, and alternative forms of communication, as well as the availability of funding for AT (Van Niekerk & Tönsing, 2015).

Therefore, it is vital that AAC systems are designed in a way that can be easily integrated into all aspects of an individual's life, such that it enables functional participation within desired contexts, being mindful of possible barriers and facilitators within each environment (Cook et al., 2019; Wilkinson & Jagaroo, 2004), while also considering macro-contextual factors in the design to ensure maximal availability and uptake.

2.4.1.4 GS-based AAC system

GS-based AAC systems can consist of a software application loaded onto a mobile technology hardware platform (non-dedicated system) or comprise a dedicated device that is designed specifically for the purpose of supporting communiction for a person with CCN (McNaughton & Light, 2013). Irrespective of the device/hardware on which an AAC system operates, an electronic GS-based AAC system typically consists of, but is not limited to, an interface that displays GS, GS that represents different referents (vocabulary), digitised and/or synthesised voice output, and access features allowing a person to select a GS in some way (Beukelman & Light, 2020).

To ensure a system's usability and general aesthetic appeal, the designer must match these various components to suit the needs/desires of persons with CCN, in addition to the cultural and linguistic background, and sensory, motor and cognitive skills of such individuals (Gosnell et al., 2011; Light, Wilkinson, et al., 2019). Therefore, the way in which the GS-based AAC system components and their respective features are used and displayed within a GS-based AAC system will differ depending on the requirements of the target population (Light & Drager, 2002; Lynch et al., 2019; Reichle & Drager, 2010).

Furthermore, the presentation of the communication options on the display of an AAC system can influence an individual's ability to navigate across a range of symbols (Reichle & Drager, 2010). With this is mind, designers must take into account multiple variables, such as the permanence of the display (i.e., whether the individual can navigate through multiple pages), the layout, such as a grid display or visual scene display (VSD), the number of representations, size, and colour of symbols that can support faster reaction times when locating a target symbol within an array of symbols, facilitate motor planning or automaticity, as well as reduce cognitive demands of the system (Reichle & Drager, 2010; Tenny, 2016; Thistle & Wilkinson, 2015). In addition, designers should consider the flexbility of a display layout in which an individual can adapt the number of cells in a grid display, or enlarge GS, depending on an individual's needs and preferences (Judge et al., 2019; McNaughton & Light, 2013).

Moreover, designers may be required to access a number of sources to obtain GS for the system they develop (Beukelman & Light, 2020). Some may develop their own representations, while others may incorporate GS from existing free or commercially available AAC symbol libraries[3] (Beukelman & Light, 2020). In many of these libraries, one word is associated with one GS (Baker & Chang, 2006; Judge et al., 2019; Nigam, 2006). However, some GS are designed to be purposefully polysemous (Phuphatana et al., 2018). These GS libraries typically consist of a limited number of symbols that are combined into sequences to represent words, for example, the Minspeak®[4] icons (Phuphatana et al., 2018).

Unfortunately, there is still limited research evidence that can guide AAC professionals and designers when selecting the most appropriate GS representations (Pampoulou, 2017). Multiple factors need to be considered and sometimes trade-offs need to be made, for example, between ease of learning and representational power of the GS (Light et al., 2004). Practical factors such as cost and availability, as well as software compatibility and requirements, may additionally limit choices (Pampoulou, 2017). Preferences are another factor to consider (Beukelman & Light, 2020; Pampoulou, 2017). One factor that may influence preference is the degree of congruence between the GS and the user's cultural, contextual and linguistic background, in addition to whether the selected representations will cover an appropriate range of language that will benefit and assist interaction (Ogletree et al., 2018; Pampoulou, 2017; Tenny, 2016).

Furthermore, the vocabulary incorporated into such AAC systems may vary depending on the skills of the persons for whom the system is intended (Judge et al., 2019). For instance, when designing for early, novice communicators, the vocabulary package incorporated into such AAC systems may be a simple one, whereby a limited number of GS represent a limited range of

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[3] Examples of AAC symbol libraries include, Imagine Symbols, Picture Communication Symbols (PCS), and Widgit Symbols to name a few (Beukelman & Light, 2020). PCS® is a product of Tobii Dynavox CCL, Pittsburgh, Pennsylvania, https://www.tobiidynavox.com/software/content/pcs-classic-symbols/. Widgit Symbols are a product from Widgit Software, Leamington Spa, Warwickshire, https://www.widgit.com/.

[4] Minspeak® is a product of Semantic Compaction Systems, Pittsburgh, Pennsylvania, https://minspeak.com/

meanings and communication functions (e.g., requests for preferred objects) (Judge et al., 2019; Tenny, 2016). On the other hand, if the system is designed for more advanced communicators with the aim of ensuring appropriate support for language and literacy development, the vocabulary package may be a complex and comprehensive one that attempts to allow a measure of novel utterance generation through access to a large vocabulary, sentence building, text that accompanies the GS, and grammatical features such as morphological variations (Judge et al., 2019; Tenny, 2016). The latter option often increases the working memory demands of the individual and should therefore be considered when matching these features to the individual's cognitive abilities (Tenny, 2016; Thistle & Wilkinson, 2013). Additionally, designers should take into account strategies such as just-in-time (JIT) programming, which allows individuals to easily customise and add context-specific vocabulary during day-to-day interactions (Schlosser et al., 2016).

Voice output (speech generation) provides auditory feedback for the individual and their communication partners upon the selection of GS (Light & Drager, 2002; Waller, 2019). This often facilitates faster communication and reduces the chances of misinterpretation of the individual's intended message (Light & Drager, 2002). Currently, AAC systems typically use synthesised speech (computer generated) and digitised speech (recording of a human voice) (Light & Drager, 2002). Designers will need to consider aspects like the intelligibility of voice output, as well as factors such as how the system will allow for voice output that can match the user's age, gender and language through voice recordings or additional voice output options (Light & Drager, 2002; Weed et al., 2011). For example, a female may prefer a female's voice as opposed to a male's voice (Weed et al., 2011).

The way in which an indidivual can access the system will depend on their physical and cogntive capbabilities as well as the selected device and system features (Murray et al., 2019). Therefore, designers may need to consider including additional access features such as a switch or an eye-gaze access feature when designing for persons with limited motor control, as opposed to only selecting GS through touching the screen of a system, which is easier for persons with no physical impairments (Beukelman & Light, 2020; Murray et al., 2019).

2.4.2 Input from users and stakeholders

In accordance with the sixth principle of HCD, continuous collaboration with a multidisciplinary team is a key factor that can inform the design process (Allen, 2005; Allsop et al., 2010; Babic et al., 2015; Boster & McCarthy, 2018). Although the input gained from various members can play a vital role in improving the outcome of a system, gaining input from multiple people with various degrees of skill and knowledge can pose its own challenges (Choi, 2011). For instance, it may lead to a scenario where designers become inundated with a host of different ideas, all of which may be too difficult or complicated to incorporate into a single design (Choi, 2011). At present, there is still no clarity on the extent to which these contributions from various stakeholders ought to be incorporated into the design (Allsop et al., 2010; Tao et al., 2020).

Moreover, the inclusion of multiple people can make identifying one's role within the team difficult, and thus the respective roles of the user and/or stakeholder and the designer may become blurred (Steen, 2011). This also extends to the roles of the individual with CCN and their stakeholders. For example, products that are designed for children (such as a GS-based AAC system) ideally require input from them to inform the design process (Allsop et al., 2010; Light et al., 2007). However, due to such children's complex communication needs, they may not be able to adequately express or provide the designer with feasible ideas for the design of a product (Light et al., 2007). In such an instance, their stakeholders (i.e., the caregivers) would step into the role of the child and provide input to the designer (Light et al., 2007). However, this runs the risk of not truly capturing the child's needs and preferences (Allsop et al., 2010).

Therefore, careful introspection and acknowledgement of one's role throughout the design process is necessary to ensure effective (and genuine) involvement from all parties (Steen, 2011). Overall, various authors have emphasised the importance of including the individual and their key stakeholders in the early stages of research and the design of technology to ensure that AT products match the individual's needs, abilities and preferences, thereby increasing AT usability (Allsop et al., 2010; Hwang & Park, 2018; Waller et al., 2005).

2.5 Methods used to obtain input and feedback

There are a variety of methods designers can use to gain information about the needs, wants and aspirations of individuals and their respective stakeholders (Tosi, 2020). Similarly, various methods can be used to gain feedback about the developed product in the evaluation stage (Tao et al., 2020). During the initial stages of the design process, methods such as searching the literature to find research evidence on a particular population or subject (Hill, 2006), interviews, focus groups, and/or ethnographic observations can be used to gain information specific to the individual and/or product requirements (Black et al., 2012; Marti & Bannon, 2009; Waller et al., 2005). In addition, information specific to the design requirements and how they influence the individual can be gained using strategies such as prototyping (Buchenau & Suri, 2000; Tosi, 2020).

The final product evaluation often requires the designer to first specify the type of evaluation construct (that is, what they are wanting to evaluate), before identifying the relevant evaluation method that will evaluate the product accordingly (Tao et al., 2020). Typically, the ultimate goal is to ensure the effectiveness and efficiency of the end-product, and to ensure user satisfaction with the product (Tosi, 2020). Therefore, usability testing is a key construct in evaluating AT products (Arthanat et al., 2007; Tao et al., 2020; Tosi, 2020). Moreover, there are other constructs, which often fall under usability that can also be evaluated separately, and include how easy the device is to use, how well the individual can use the system (i.e., the user's performance), and how well the system performs during specific tasks (Tao et al., 2020; Tosi, 2020).

There can be an overlap in the types of methods used to gain information during the initial stages of the design process, and the methods used to evaluate products such as interviews, questionnaires/surveys, and observations (Magnier et al., 2012; Tao et al., 2020). However, there are some evaluation methods that are typically specific to evaluating system characteristics and system effects (Tao et al., 2020). These include System Usability Scale (SUS) surveys and experience prototyping (that is, allowing an individual to use a prototype or product in order to evaluate it) (Buchenau & Suri, 2000; Tao et al., 2020; Tosi, 2020).

As the design process is often iterative, these methods used may be repeated or changed per iteration, and thus multiple methods can be used within a design process (Tosi, 2020). Furthermore, the methods used throughout the design process may vary depending on contextual factors such as time, cost and access to materials/resources, as well as the population for whom the product is designed (Choi, 2011; Tosi, 2020). Due to the complexity of the target population, designers may face challenges in obtaining or interpreting feedback from persons with CCN when using traditional information gathering or evaluation methods (Brischetto, 2020; Dell'Era

& Landoni, 2014). Therefore, it is important for designers to determine which method would be the most efficient and effective to use, or alternatively, adapt the ways in which traditional methods are used in order to facilitate the involvement of persons with CCN within the design process (Nilsson et al., 2015).

2.6 Conclusion

It is evident that designing a GS-based AAC system is a daunting and complex task (Choi, 2011; Light & Drager, 2002). Designers need a sound understanding of the heterogeneous target group of individuals, the complex task of communication interaction and language development to be accomplished through the use of the system, as well as the diverse contexts of use (Cook et al., 2019; Ogletree et al., 2018; Reichle & Drager, 2010). While advances in computing and mobile technology have made many features possible within these systems, this further adds to the complexity of design decisions and processes.

Considering that there are several aspects and various information sources that need to be incorporated, there is no correct singular method of designing a system. Moreover, the lack of clarity regarding the extent to which the individual and their input is considered within a product design, the interchangeable use of HCD terminology, and a wavering approach to HCD makes identifying and using a particular design method difficult (Sanders & Stappers, 2008; Steen, 2011). Therefore, conducting a scoping review to map the literature and provide an overview of documented design approaches and principles, methods, input obtained for the design process, and concomitant outcomes of GS-based AAC system design will facilitate an understanding of the current state of the field. Future AAC system designers and developers can become aware of possible methods that could facilitate the design process. Stakeholders can also understand the current state of the field and can be empowered to interrogate the design processes used during GS-based AAC system design before product purchase.

3 METHODOLOGY

3.1 Research aims

3.1.1 Main aim

The aim of this scoping review is to describe the design approaches and principles, methods and input considered within design studies, as well as identify the concomitant product outcomes that are documented in the literature with regards to the design of electronic GS-based AAC systems.

3.1.2 Sub-aims

The sub-aims of the study are:

i. To describe the AAC system features designed;
ii. To describe the design approaches (models) used;
iii. To determine to what extent design methods comply with the six HCD principles as set out in the ISO 9241-210 standard (ISO, 2019);
iv. To describe the input obtained and used during the design process;
v. To describe the persons involved in the design process (who is involved, stages at which they are involved, methods of engagement, and roles played);
vi. To describe product evaluations and outcomes; and
vii. To describe the limitations and future recommendations reported.

3.2 Research design

A scoping review was conducted to identify and synthesise relevant and current literature relating to the design approaches and principles, methods and input considered within design studies, as well as identify the concomitant product outcomes that are documented in the literature regarding the design of electronic GS-based AAC systems. The main aim of a scoping review is to map key concepts that underpin broad areas of research that are complex and heterogenous in nature, irrespective of the quality of the studies (Colquhoun et al., 2014; Peters et al., 2015; Tricco et al., 2016). As the AAC population is heterogenous in nature and the topic presented above is complex and inconsistently defined, a scoping review methodology was deemed relevant for this study.

Section 3: Methodology

The scoping review procedure was guided by the methodological framework developed by Arksey and O'Malley (2005) and enhanced by Levac et al. (2010). However, the optional sixth stage (consultation with stakeholders) of this methodology was not conducted. An overview of the six methodological stages is given in Figure 1.

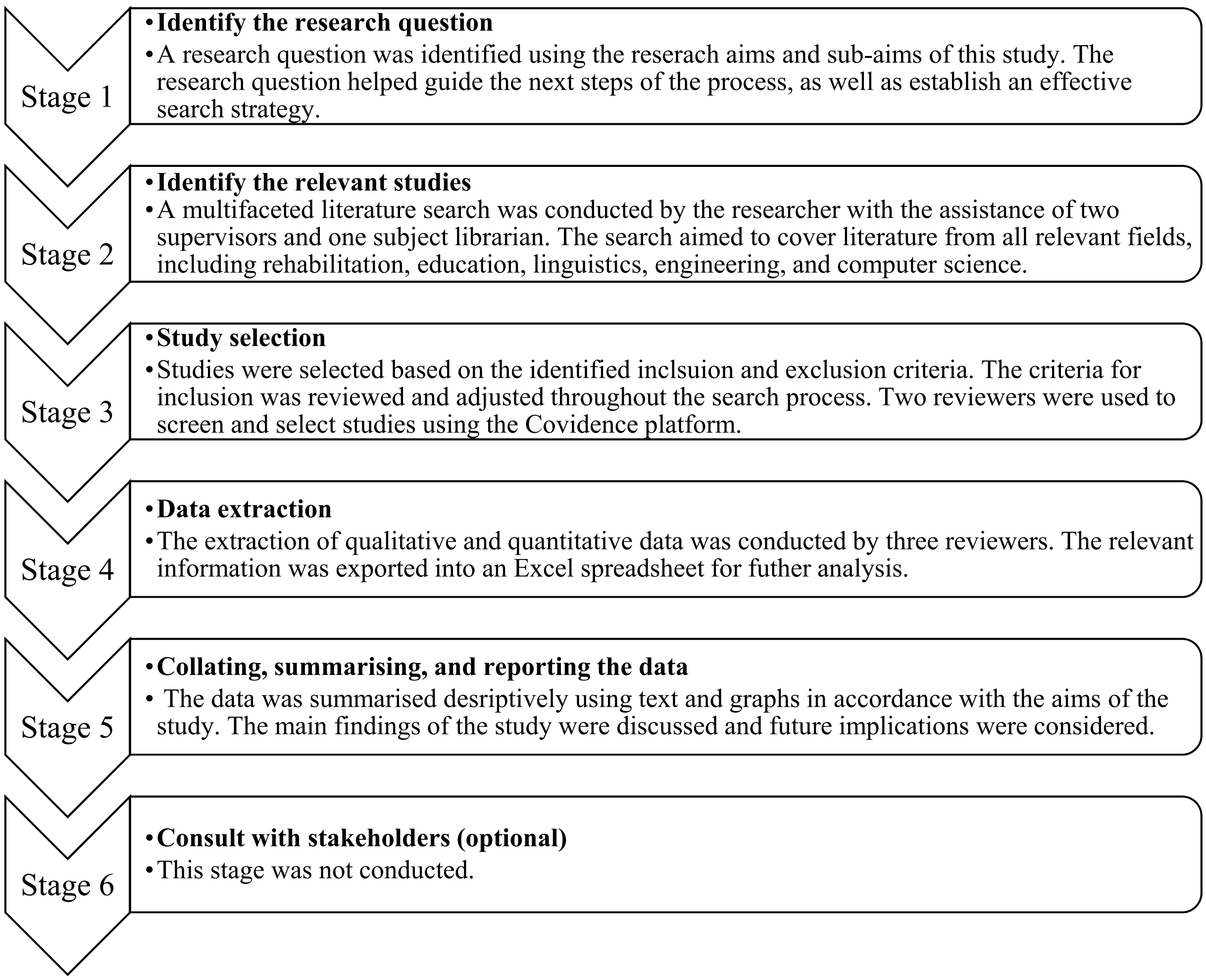

Figure 1. Overview of the six stages of Arksey and O'Malley's (2005) methodological framework.

Additionally, this scoping review was structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist suggested by Tricco et al. (2018). In following a strict protocol, a rigorous and transparent review and accurate, consistent reporting of results was ensured (Colquhoun et al., 2014; Tricco et al., 2018).

3.3 Ethical considerations

As per the requirement of the University of Pretoria, ethical clearance for this study was obtained from the Faculty of Humanities (Appendix A). An editorial change to the original title, as noted in the proposal, was approved by the relevant committees.

A scoping review does not entail the direct use of participants but rather the identification, appraisal and synthesis of current and relevant literature (Peters et al., 2015). Nonetheless, there are ethical factors to be considered, such as researcher bias, reliability and accuracy of data extraction, and plagiarism.

By following a strict scoping review protocol and methodological framework, the researcher could ensure transparency, allowing for the review to be replicated, thereby ensuring accuracy. In addition, to avoid researcher bias and improve accuracy of data extraction, multiple data bases were searched, and each study was screened and selected by two reviewers, with a third reviewer used as an arbitrator. Lastly, the use of the PRISMA-ScR checklist increased the transparency of the methods used and contributed to accurate reporting (Colquhoun et al., 2014; Tricco et al., 2018).

The data collected was reported accurately, avoiding any changes to the intended meaning or modifying results (Wager & Wiffen, 2011). The data was not reported verbatim and references accompanied the data extracted from each citation in order to avoid plagiarism (Wager & Wiffen, 2011).

3.4 Protocol

Using the aims and rationale for the study, a search protocol was developed to guide the identification and selection of studies which encompass stages two to three of Arksey and O’Malley's (2005) methodology. The search protocol was refined and adjusted throughout the review. Appendix B provides the final search protocol with the adaptations made throughout the review process.

3.5 Pilot study

A multifaceted pilot search was conducted in order to assess the feasibility of the search terms, inclusion and exclusion criteria, and the extraction tools used within this study (Tricco et al., 2016). Appendices C, D, E, F, and G illustrate the first stage of the pilot searches that were conducted and show how the search terms were refined and adjusted over time. The second stage of the pilot search included a comparison of three search strings between various databases to determine which search string provided more consistency in terms of the results yielded and the possible hits found per search (Appendix H). The search string that provided more feasible results was selected and used in the review.

The third stage of this pilot search was to identify whether the inclusion and exclusion criteria selected were easy to interpret and apply within the screening process and whether it was relevant to the study. Each stage of the pilot search encompassed a team meeting whereby feedback was discussed with the author and supervisors, and recommendations were provided. Table 1 outlines the aims, outcomes and recommendations of this pilot study. The recommendations were then included within the main study.

Table 1

Pilot Search Aims, Procedure, Findings, and Recommendations

Aim	**Procedure**	**Results**	**Recommendations**
To determine whether the search terms are applicable.	A search was conducted using the provisional terms identified in the search protocol (Appendix B).	There were many irrelevant citations found. Many citations were related to either the customisation of devices or were based on technology/computer-based studies that were not specific to AAC systems. Medically based citations that included genomics, DNA, and viruses were also identified within the search results. The use of population significantly reduced the number of citations yielded, which removed many possible hits. The use of search terms such as software, picture and symbol created an unfeasible number of citations yielded. The use of the terms ‘design’ and ‘development’ in isolation included citations that consisted of the design (methodology) of studies themselves and not design of a product.	Removed: - Population i.e., “severe disability”, “complex communication needs”, “communication disabilities”, “special needs” - “assistive device”, “software”, “electronic device” - “picture”, “symbol” Added: - “design process”, “development process” - NOT Boolean function to exclude: a) Alternative AAC abbreviation meanings i.e., advanced audio coding. b) Technology-based or engineering terms such as “MIMO communication”, “AAC decoder”, “algorithms”, “mathematical models/analysis”, “support vector machines”, computational biology, algebra, “signal processing/transduction”, “sequence analysis”, “data compression”, “sensors”, “bandwidths”, and “data mining”. c) Medically based terms such as “protein”, “amino acids sequence”, “deoxyribonucleic acid DNA”, “genomes”, “gene expression/sequencing”, “bioinformatics”, “drug resistance”, “neural networks”, “bacteria”, “antibiotics”, “enzymes”, “peptides”, “binding sites antimicrobial agents”, “infections”, “molecular sequence data”, “viruses”, “eyes/eyesight”.

Aim	Procedure	Results	Recommendations
To determine which databases to search.	Databases were selected from various relevant fields, such as rehabilitation, education, linguistics, engineering, and computer science. The search terms were trialled per database to assess the feasibility of the results/hits yielded.	Databases that provide a wider scope of relevant fields were required to broaden the search results. Databases relating to science were also required. Some databases were difficult to use and provided minimal hits per search string.	Databases added: - Springerlink - Web of Science Databases removed: - Science direct - Emerald Insight - Abledata - Rehadat
To review the inclusion and exclusion criteria.	26 articles were selected at random and were screened on Covidence, using the inclusion and exclusion criteria, as seen in the *Title and Abstract Screening Tool* (Appendix I). The inclusion and exclusion criteria were reviewed and adapted throughout the piloting process.	The structure of the inclusion and exclusion criteria table needed to be adjusted to help clarify the population, issue and outcome of the criteria for inclusion. The inclusion criteria needed to be specific and clear. The term 'graphic symbols' was vague and thus there was a need to provide a definition. The evaluation of designed products was omitted.	The three aspects; population, issue and outcome, should be included within the inclusion and exclusion criteria format. Include population within criteria. Population should include persons with CCN, e.g., persons with cerebral palsy, autism spectrum disorder. Population should exclude persons without CCN and persons with learning disabilities such as dyslexia. A definition of a GS-based AAC system is required. Include the evaluation of products designed as an inclusion criterion.

3.6 Inclusion and exclusion criteria

The inclusion and exclusion criteria was reviewed and refined before beginning the final stages of the title, abstract and full-text review process (Levac et al., 2010). As per the recommendations provided in Section 3.5., Table 2 provides the final inclusion and exclusion criteria that was used to select studies for this review. 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.

Table 2

Criteria for Inclusion of Studies

Aspect	Inclusion	Exclusion	Justification
Population	Persons with CCN. This can 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) (Boster & McCarthy, 2018; Waller, 2019).	Children/adults without disability. Persons with learning impairments such as dyslexia.	GS-based AAC systems aim to support expressive communication and comprehension for persons with CCN (Judge et al., 2019).
Issue	Describes the design and/or development process of a GS-based AAC system.	Describes only customisation, testing, or implementation of a GS-based AAC system.	There is no clear outline for AAC system developers that can inform the design process (Judge et al., 2019). Therefore, mapping information regarding the design process could prove beneficial for future designers.
	Describes the input obtained and used within the design process. Examples of input include: • Stakeholder input, • research evidence, • ethnography (observations in environment and task).	Information regarding the input obtained and used within the design process is omitted.	According to Dubberly (2004, p. 12), all design processes commence with a form of input. There is minimal information on which data sources should be considered and to what extent the data is used during the design process (Magnier et al., 2012). Therefore, the aim is to provide an overview of the input obtained and used within the design process.

Aspect	Inclusion	Exclusion	Justification
Issue	Describes an evaluation process and the extent to which the product outcomes reflect the needs of the target population.	Information on the outcome and evaluation of the product design is omitted.	The aim of a design process is to achieve an outcome, in this case, a useful product (Dubberly, 2004). If there is no evaluation of usefulness or an aspect of usefulness, it remains unclear as to whether the outcome has been achieved. Therefore, a description of the outcome and an evaluation of it are seen as an integral part of the design process.
Outcome	The outcome of the design process is an electronic graphic-symbol-based AAC system.	Describes the design and development of any other AAC systems, such as: • Electronic text-based systems • Non-electronic systems.	Due to the many advances in computing and mobile App technology, electronic dedicated and non-dedicated AAC devices have become a popular option for persons with CCN (McNaughton & Light, 2013; Waller, 2019). Therefore, it would be important to understand the state of the science in AAC GS-based design.
Date of publication	2000 – 2020	Records published prior to 2000	The recent advances in mobile technology have led to a proliferation of new, available AAC systems (McNaughton & Light, 2013). Therefore, it important to review the most up-to-date literature on GS-based AAC system design.
Language	English	Language other than English	Due to limited time and resources, translation of studies was not feasible (Gough et al., 2017).

3.7 Materials and equipment

The main tools required for this scoping review included a laptop and internet access. In addition, access to the University of Pretoria's online library portal was also required to search multiple databases. Covidence, a web-based software platform (Veritas Health Innovation, 2019), was used for the screening and selection of citations at an abstract and full text level. The Covidence software is not only a time-effective screening, it also reduces the risk of bias by allowing two researchers to screen and select citations (Veritas Health Innovation, 2019). Microsoft Word was used to create this document, as well as the inclusion and exclusion criteria, which was then uploaded into Covidence. In addition, Microsoft Excel was used to create a data extraction spreadsheet whereby all the relevant reviews could use to extract data.

3.8 Search strategy

A comprehensive and multifaceted literature search was conducted by the researcher with the assistance of supervisors, one subject librarian, and an international expert. The search aimed to cover literature from all relevant fields, including rehabilitation, education, linguistics, engineering, and computer science. The subject librarian and international expert were asked to give input on the relevant online databases and platforms. The search methods included searching individual databases (e.g., Computer Science Database), as well as searching database platforms such as ProQuest and EBSCOhost. Relevant databases were searched using the following Boolean search string: *("augmentative and alternative communication" OR AAC OR "alternative communication") AND ("design process" OR "development process").*

A Really Simple Syndication (RSS) feed and search alerts were used to receive new, update-to-date literature that may be relevant to the research study (Ovadia, 2012). The RSS feed and email alerts were initiated on the same day as the initial results were exported (i.e., 4 November 2020) and ended in January 2021. Results from these searches were collected and screened along with the original results yielded. Table 3 illustrates the final search strategy and number of citations generated per database, including the results yielded from the RSS feed.

Table 3

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

Database	**Search strategy**	**Initial yield**	**RSS Feed**	**Total (minus duplicates)**
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
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

Lastly, 22 additional sources were obtained from hand-searches from the reference list of identified articles found in the yielded results and a general search using the Google/Google Scholar search engine.

3.9 Selection of studies

The systematic search yielded a total of 3,725 records. Search results were downloaded into an RIS format and were imported into Covidence. A total number of 467 duplicates were removed, and 3,258 records remained for title and abstract screening.

The title and abstract screening was completed using Covidence. Each record was independently screened by two reviewers. The student (author) screened all records. The supervisor independently screened 2,189 records, and the co-supervisor screened the remaining 1,069 records. When screening a record, the title and abstract were read and compared to the established inclusion and exclusion criteria (see Section 3.6). Based on the record meeting or not meeting these criteria, the researchers then indicated 'yes', 'no', or 'maybe' to determine whether the record should be included or excluded for full text screening. In the event that both reviewers answered 'maybe', or if one reviewer answered 'yes' and the other answered 'maybe', the record was included within the full-text screening. However, if one reviewer answered 'maybe' whilst the other answered 'no', this was noted as a disagreement.

After each record had been independently reviewed by two reviewers, any disagreements between reviewers were discussed in an online meeting, and consensus was reached as to whether to include or exclude the record. After screening all records on a title and abstract level, a total of 103 records were advanced to full text screening. Full text screening also took place on Covidence. Once again, each record was independently screened by two reviewers, namely the student and the supervisor. The same inclusion and exclusion criteria were used and a total of 28 records were selected for final data extraction. Reasons for exclusion of 75 records at the full-text level included:

- The citation does not address the design and/or development of a GS-based AAC system (44 citations).
- Information on the outcome and evaluation of the product design is omitted (15 citations).
- Information on the design and development process of a GS-based AAC system is omitted (seven citations).
- Date of publication is prior to 2000 (four citations).
- The product is not described (three citations).
- Duplicate (two citations).

The search decision process and results were documented using Moher et al.'s (2010) PRISMA flow diagram structure, as seen in Figure 2.

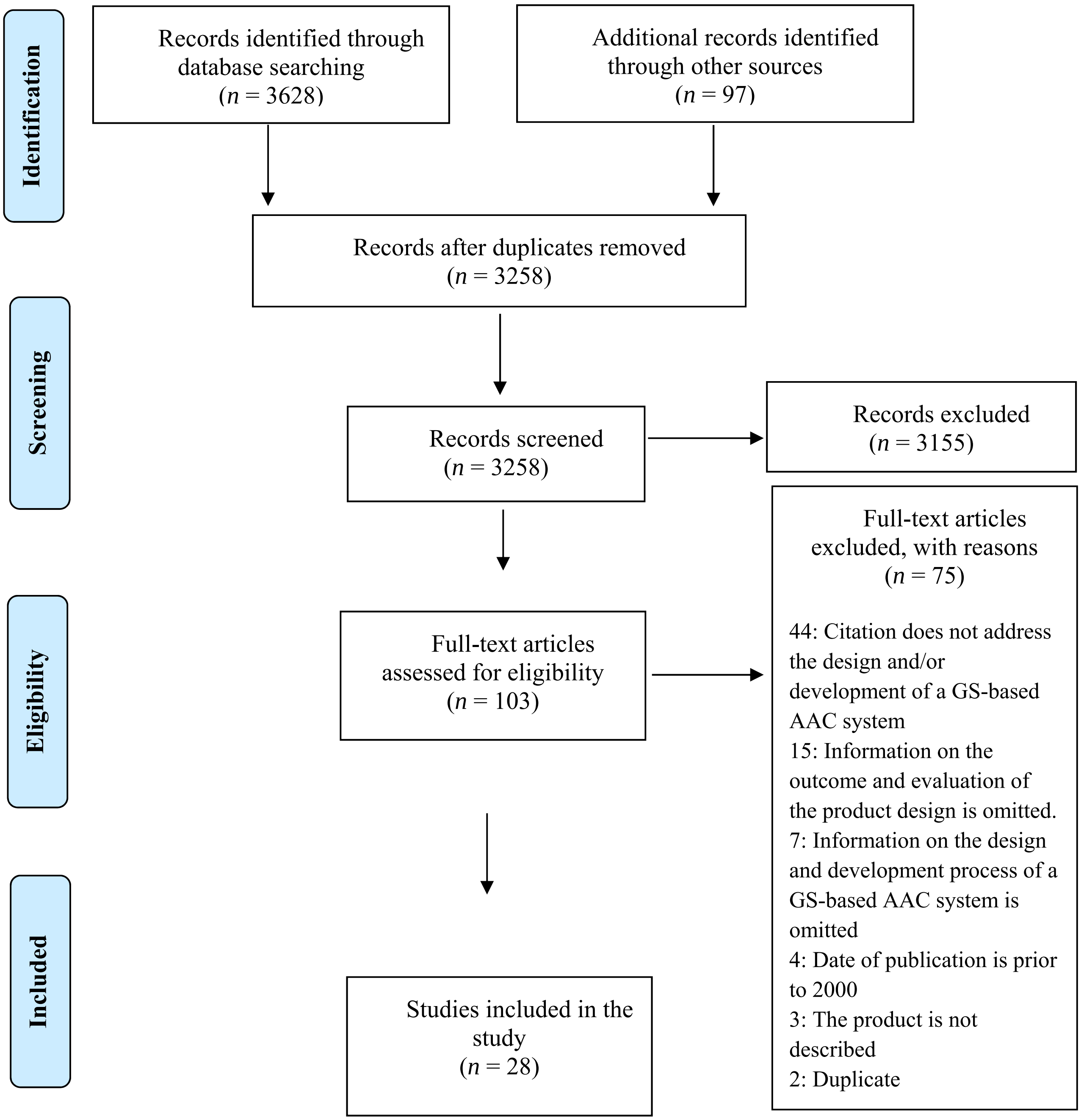

Figure 2. PRISMA flow diagram of selection process.

3.10 Data extraction

Descriptive data was extracted in accordance with the sub-aims of this review to provide an overview of the literature pertaining to design studies of GS-based AAC systems. The data extraction form identified the data relevant to the aims and sub-aims of this review and was developed in the form of a Microsoft Excel spreadsheet (Arksey & O'Malley, 2005; Levac et al., 2010). The form is given in Appendix J. Table 4 presents an overview of the main categories of data that were extracted.

Table 4

An Overview of the Main Categories for Data Extraction

Category of data extracted	**Justification**
Characteristics of the research study	To describe the author and date of the study, the aims of the study, and the authors' disciplinary and/or institutional affiliation, as well as where the study took place. Additionally, to describe the product or prototype that was designed.
Description of the AAC system features designed	To describe the features of the system designed.
Design methods (approaches) and principles	To describe the design approaches used as well as the frequency with which they were used with specific focus on the six HCD principles.
Input obtained	To determine how and where information is sourced with specific focus on the input that is obtained by designers to better understand the user (population), the task, and the contexts in which the system may be used.
Persons involved within the design process	To determine to what extent the individual and their stakeholders were included within the design process, specifically looking at their role, what step/s of the process they were included in, and how they were included.
Product evaluation and outcomes	To describe the evaluation of the product design including how the product is evaluated, what constructs are evaluated, and the extent to which the product meets the needs of the target population.
Limitations and recommendations	To determine the extent to which designers experienced limitations that may have influenced decision-making/design processes, and to identify the recommendations for further research and/or development.

Two research assistants, both of whom are speech-language therapists (SLT) and have their master's degrees in AAC, were appointed to act as 'second reviewers' for data extraction. Prior to the data extraction process, the two research assistants were provided with a verbal explanation of the information required for data extraction, as well as the research proposal for additional information. Each assistant received the same Excel document, which included the data extraction form and information relating to the data needing to be extracted (included in Appendix J). Furthermore, additional definitions were included within the Excel data extraction form to ensure appropriate understanding of the data to be extracted.

The author, supervisor and two research assistants extracted data from the 28 citations included within this review and analysed the data using descriptive statistics. The author extracted data from all 28 studies, while the research assistants extracted data independently from the same 28 studies (one assistant extracted data from 14 studies and the other from 13 studies respectively). Data from the first article was extracted independently by the supervisor and author. To ensure reliability, the same article was then used as an example to explain the data extraction to the research assistants. The data extracted was then compared and conflicts were discussed. If consensus could not be reached, the supervisor acted as an arbitrator.

3.11 Reliability and validity

Data reliability and validity refers to the consistency and accuracy of the results obtained between reviewers (McMillan & Schumacher, 2014). To ensure reliability, the author and supervisor piloted, agreed on and clarified the inclusion criteria prior to the abstract and full text screening process. Records were screened for inclusion and exclusion by two independent reviewers on abstract and full text level. Also, data from the 28 selected studies was extracted independently by two persons. As discussed in Section 3.10, the same information was provided to both reviewers to ensure reliability and validity.

Percentage agreement for the inclusion and exclusion process, as well as the data extraction process, was calculated using the following percentage agreement equation (Gisev et al., 2013):

$$\frac{\text{Agreements}}{\text{Agreements+Disagreements}} \text{ x } 100$$

Accordingly, the agreement between the author and supervisor/co-supervisor was 97.3% for the title and abstract screening and 83.4% for the full text screening. The initial agreement on data extraction before reaching a consensus was 89%. The author and the two respective research assistants compared results and reached consensus on most aspects, resulting in an agreement of 99.5%. The supervisor acted as arbitrator in the remaining 0.5% of disagreements.

4 RESULTS

The purpose of this section is to present the results from the review. Data extracted from the 28 identified records is synthesised and summarised according to the sub-aims of this review. Data relating to seven areas of interest will be reported, namely the characteristics of the design studies, the features of the systems designed, the design approaches and principles used, the input obtained before and during the design process, involvement of various persons including users and stakeholders in the design process, product evaluations and outcomes, and the limitations and recommendations provided within these studies.

4.1 Characteristics of the studies included within the review

Table 5 provides an overview of the characteristics of the 28 studies included within this review. The first four columns specify the author and date of the study, the aims of the study, and the authors' disciplinary and/or institutional affiliation, as well as where the study took place. The next two columns provide details about the product or prototype that was designed. The name and a brief description are provided, as well as the primary language used in the system.

In terms of the number of publications from 2000 – 2020, it can be noted that there is an increase in the number of publications per year from 2011 – 2020, with a total of 20 of the studies published during this time frame. Only three of the studies were published between 2000 – 2005 and five between 2006 – 2010.

Most studies included researchers from a wide range of disciplines/institutions. Most of the authors were affiliated to institutions such as computing (computer science), engineering, art and design, and technology. Few studies had authors in disciplines such as communication science and disorders, as well as rehabilitation and education. Authors from these disciplines were involved in only five of the 28 studies.

It is evident from Table 5 that the studies took place in various locations. A total of 12 studies took place in a European country such as Italy, Portugal, Spain, the United Kingdom, and the Netherlands. Fewer studies were based in Asian countries (n = 8) such as Japan, China, and India. The remaining studies were conducted in North American (n = 4) and South American (n = 4) countries. No studies were conducted in any African country or in Australia.

The language of the system, the target population and the description of the product designed will be discussed in the sections to follow.

Section 4: Results

Table 5

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

Author	Aim	Disciplinary/institutional affiliation	Country	Name and/or description of product designed	Language
Al-Arifi et al. (2013)	To describe the development and evaluation of an iOS AAC application for Arabic-speaking individuals with speech impairments.	Computer and Information Sciences	Saudi Arabia	Touch-to-Speak, a prototype of an iOS-based AAC application for an iPad.	Arabic
Allen (2005)	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	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. (2017)	To describe the development and evaluation of an AAC mobile app (Yuudee) in the Chinese language.	School of Life Sciences, National Institute of Biological Sciences, Stars and Rain Education Institute, Academy of Arts and Design, and Center for Bioinformatics	Mainland China	Yuudee, an iOS- and Android-based AAC application.	Chinese
Babic et al. (2015)	"To propose software development process for AAC applications, that follows specific principles to successfully implement all functional and accessible features that applications should contain in order to be accessible and highly usable" (p. 2).	Faculty of Electrical Engineering and Computing	Croatia	Komunikator+, an iOS- and Android-based AAC application.	Croatian
Bhattacharya and Basu (2009)	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	Sanyog, an icon-based communication aid built for a Desktop PC with a 17-inch monitor.	Hindi and Bengali

Author	Aim	Disciplinary/institutional affiliation	Country	Name and/or description of product designed	Language
Boyd-Graber et al. (2006)	To describe the design and preliminary evaluation of a hybrid desktop-handheld system developed to support individuals with aphasia.	Computer Science	Montréal, Québec, Canada	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. (2014)	To present a mobile AAC application (MAAC) for disabled people.	Department of Computing	Hong Kong SAR	Mobile augmentative and alternative communication application (MAAC), an iOS- and Android-based AAC application for smartphones and/or tablets.	Chinese
da Silva et al. (2018)	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	AACVOX, an iOS- and Android-based AAC application.	Not specified
de Faria Borges et al. (2014)	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	A high-fidelity prototype of an AAC application designed for a computational device such as a tablet.	Portuguese
Daemen et al. (2007)	To describe the design and evaluation of a storytelling application for individuals with expressive aphasia.	User System Interaction and Industrial Design	Netherlands	A prototype storytelling AAC application developed in PC Macromedia Director and loaded onto a tablet PC with a webcam attached.	English

Author	Aim	Disciplinary/institutional affiliation	Country	Name and/or description of product designed	Language
de Oliveira et al. (2016)	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	VoxLaps, an AAC application designed for any Android system.	Portuguese
Di Mascio et al. (2019)	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, and the Center for Autism	Italy	A prototype of an AAC application for persons with ASD designed for a tablet and/or smartphone.	Not specified.
Hayes et al. (2010)	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	Mocotos, a prototype of a mobile visual AAC aid, consisting of software loaded onto a Nokia tablet.	English
Hervás et al. (2020)	To present the design and evaluation of an AAC system's prediction mechanisms aimed for the composition of messages using pictograms.	Faculty of Informatics, Technical College, and the Institute of Knowledge Technology	Spain	PictoEditor, an AAC application designer for a tablet.	Spanish
Hill (2006)	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	A prototype of a Mandarin Language System designed for a (presumably dedicated) SGD.	Mandarin
Hine et al. (2003)	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	A multi-media AAC application loaded onto PDAs.	English

Author	Aim	Disciplinary/institutional affiliation	Country	Name and/or description of product designed	Language
Hirotomi (2018)	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	Stalk2, an AAC application designed for an Android OS system.	Japanese
Jafi et al. (2020)	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	Esmaany ("Listen to Me"), a low-cost, gaze interaction-based Arabic language application designed for Microsoft Windows PCs.	Arabic
Karita (2017)	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	Friendly VOCA, an AAC application that is compatible with iOS devices.	Japanese
Lubas et al. (2014)	To provide an example of the user-centred (by proxy) design process used to develop an AAC application for children with communication impairments as a result of ASD.	College of Health Sciences (Social work)	USA	I Click I Talk, an AAC application designed for Apple and Android devices.	English
Mahmud et al. (2013)	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	The Netherlands	CoCreation, a prototype of an AAC application intended for a PDA or a tablet.	Dutch
Martin et al. (2019)	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	Spain	Today I Tell, a prototype of an AAC application designed for a smartphone and/or tablet.	Spanish
Mendes and Correia (2013)	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	Vox4all®, an AAC application designed for a smartphone and/or tablet.	Not specified

Author	Aim	Disciplinary/institutional affiliation	Country	Name and/or description of product designed	Language
Rodríguez-Sedano et al. (2017)	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	An AAC software prototype, Visual Language (VILA).	English and Spanish
Saturno et al. (2015)	To mitigate communication problems of children and adolescents with CP through the development of an AAC tool.	Applied Computing Department	Brazil	A prototype of an AAC computer-based solution.	Portuguese
Stančić et al. (2013)	To present the development of an iPad-based AAC application ('Communicator').	Education and rehabilitation sciences, electrical engineering and computing, humanities and social sciences, graphic arts	Croatia	Communicator, an AAC application designed for an iPad.	Not specified
van de Sandt-Koenderman et al. (2005)	To develop a portable computerised communication aid for aphasic people to support communication in everyday life.	Rehabilitation Medicine, Speech and Language Therapy Research Unit	UK, Portugal, Netherlands	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
Williams et al. (2015)	To investigate the design of vocabulary prompts on a head-worn display for individuals with aphasia.	Information Studies, Life Enhancement	Korea	A head-worn glass AAC (GLAAC) prototype which is an Android-based AAC application for Google Glass.	Not specified

4.2 Description of the AAC system features designed

Data was extracted based on the type of AAC system designed, the physical aspects of the system, the display features, language features, voice output settings, and access features. A summary of the main characteristics of the electronic GS-based AAC systems that were described in the studies is provided in Appendix K. A brief description of the results regarding the main characteristics is also provided.

4.2.1 Type of AAC system designed

Most of the GS-based systems designed (*n* = 26) were AAC applications designed to be uploaded onto mobile technology such as a computer, PDA, smartphone and/or tablet. Only two studies reported on the design of dedicated systems which included hardware such as a dedicated SGD (Hill, 2006), and a book with an icon keyboard, a waist pack and a mobile speaker unit (Allen, 2005).

Despite all of the studies reporting the type of device/hardware that will accommodate the designed GS-based AAC systems, only 11 studies reported on the portability of the device. For example, Williams et al. (2015) discussed portability in terms of size, as they designed a head-worn display that was easy to carry around and less distracting to users and partners. Allen's (2005) study reported on light sensitivity in addition to portability. He discussed the system's ability to automatically switch on "back-lighting of the screen and keyboard" when there is low ambient light (Allen, 2005, p. 141). The look of the system to try to reduce the negative social perceptions that are associated with other AAC devices was reported in two studies (Allen, 2005; Williams et al., 2015). One study focused on the adaptability of the system interface and discussed how it would be able to be used on various screen resolutions of different devices (Cheung et al., 2014).

4.2.2 Display

Appendix K shows that many of the studies (*n* = 17) reported using a dynamic, grid display. Fewer studies (*n* = 5) made use of dynamic VSD in their design of a GS-based AAC system. Three studies did not report the type of display designed and two studies did not specify the type of display layout (e.g., grid display or VSD).

The text displayed on a screen and used in correlation with the graphic symbol as well as the number of cells used in the display of such a system was reported in 15 and 14 studies respectively. Out of the 15 studies that included text, only three reported on the customisation of the font or size of the text. Similarly, out of the 14 studies that reported on the number of cells per display, only four studies reported on their system allowing for the number of cells per display to be adjusted. For example, An et al. (2017) designed a customisable GS-based system where the number of cells can vary between one to nine cells per display.

The number of cells per system varied throughout each study and included variations such as 18 icons in three rows (Bhattacharya & Basu, 2009), five columns, with 12 cells per column (Hirotomi, 2018), and six pictures within a cluster (Mahmud et al., 2013). Jafri et al. (2020) designed the visual interface so that it can flow from right to left according to Arabic language.

4.2.3 Graphic symbols

The majority (*n* = 23) of the studies described systems that included GS from an AAC symbol library. Commercially available symbol libraries that were reported included PCS, the Aragonese Centre of AAC (ARASAAC), Lingraphica, and Widgit symbols. Few studies (*n* = 2) reported on systems incorporating other images that included symbols from clipart. A total of 19 studies incorporated photographs within their system design, these included pictures of real-life objects, events or people taken by the individual using the device or the internet.

Types of customisations include aspects such as downloading or capturing personalised pictures accompanied by voice recordings and text as seen in studies such as Cheung et al. (2014) and Boyd-Graber et al. (2006). Semantic compaction (that is, GS that have polysemous semantic meanings) was reported in Hill's (2006) study. Few studies reported on the size of the symbols (*n* = 8) and the same was observed with colour coding symbols (*n* = 7). Colour coding techniques included the use of the Fitzgerald key to categorise vocabulary, as seen in de Oliveira et al.'s (2016) study. Hervás et al. (2020) included a similar strategy and coloured coded vocabulary categories that correspond to the respective ‘part-of-speech tags’ (p. 5653). Five studies included additional display features such as the use of bright colours to maintain children's attention (Martin et al., 2019), categorising pictures based on the time they were taken (Mahmud et al., 2013) or changing the GS based on location (Karita, 2017).

4.2.4 Vocabulary features

The vocabulary (i.e., information about the type and number of words/messages and/or parts of speech) included within each system was often not explicitly discussed. However, the incorporation of core words and fringe words was discussed in two studies and one study, respectively. 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. Customisation also included aspects such as changing the vocabulary sets based on location (Karita, 2017), JIT vocabulary (Hirotomi, 2018), and adjusting vocabulary based on class subjects such as mathematics (Saturno et al., 2015). Additional features such as word or sentence prediction ($n = 3$) and access to morphology or syntax ($n = 3$) were also reported.

4.2.5 Voice output settings

Synthesised or digitised voice output as part of the GS-based AAC system were reported by nine and seven studies respectively. AAC systems that include both synthesised and digitised voice output were reported in eight studies. Only four studies did not specify the type of voice output included. For example, de Faria Borges et al. (2014) stated that sentences are to be 'voiced' but did not report which form of voice output would be included. Allen (2005) was the only study that specifically mentioned amplification, in this case "digital volume control" (p. 142), within his system design.

4.2.6 Access

When it comes to the type of access used, the majority of the studies ($n = 21$) reported using touch screens as a way in which an individual can access specific GS representations 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 rarely included. Two studies were not explicit about the type of access feature. For example, Mahmud et al. (2013) stated that the indidivual can select and drag images but they did not specify what form of access feature they would use to accomplish this task. Three studies did not report on the form of access at all.

4.3 Design approaches and principles

4.3.1 Design approach

The main intention of this section was to extract data on the design approaches used within each study that would guide the design process. A total of 20 studies specified the design approach used, while eight studies did not specify this. It is evident in Figure 3 that few studies (n = 5) made use of an HCD approach. Martin et al. (2019) discussed using HCD; however, did not specify which HCD approach they used to guide the design. The only HCD subtype that was reported was a participatory design approach – used in four studies.

However, each author reported a variation of the approach and/or used different terminology. Allen (2005) reported on a "Designer-facilitated Participatory Design" (p. 137), Boyd-Graber et al. (2006) discussed using a modified version of a participatory design approach, and de Faria Borges et al. (2014) reported on an adapted "participatory design method for customised assistive technology [PD4CAT]" (p. 1). Hayes et al. (2010) was one of two studies that reported a mixed methodology approach and reported on both a participatory design approach and a UCD approach. HCD approaches like ethnography design, contextual design, lead user approach, co-design, and empathetic design were not reported. A UCD approach was reported in eight additional studies. A total of six studies referred to other approaches or frameworks that guided the design of the system. This included two studies which reported using a mixed methodology, of which one study has already been discussed. An exploratory design approach was reported by both Williams et al. (2015) and Mendes and Correia (2013). In addition, a longitudinal approach (Hirotomi, 2018), an action research methodology (Di Mascio et al., 2019), an evidence-based practice approach to design (Hill, 2006), and a UserFit methodology (Hine et al., 2003) were reported.

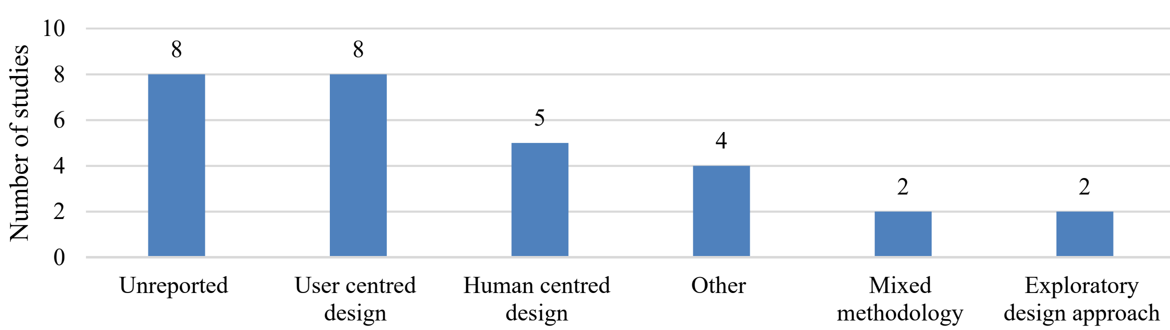

Figure 3. Design approaches used to guide the design process.

4.3.2 Human centred design principles

The information gathered in this section was based on whether authors followed one or more of the six HCD principles as set out by the ISO 9241-210: 2019 standard as cited in Shekhovtsova et al. (2020). Due to the somewhat vague nature of the principles reported, even limited evidence that a certain principle was addressed was accepted when making the judgement.

Only 11 studies complied with all six HCD principles. Interestingly, there were only five studies where authors pertinently stated that they were using an HCD approach. This indicates that designers do not necessarily have to state that they are following an HCD approach to comply with the six HCD principles. Out of the eight studies that reported using a UCD approach, only three followed all six HCD principles. The three additional studies that complied with these principles used other design approaches. While Di Mascio et al. (2019) used an action research approach, they also made mention of UCD within the literature. Mahmud et al. (2013) reported on participatory design but did not explicitly state that they had used it, and Williams et al. (2015) used an exploratory design approach.

Regarding the specific principles, the majority (*n* = 26) of the studies, as shown in Figure 4, reported on the inclusion of the end-user and/or their relevant stakeholder/s within the design process. In addition, many studies (*n* = 26), mentioned that team members from multiple disciplines were involved within the design. However, the persons involved within each study as well as their roles differed quite substantially. Although most studies (*n* = 22) presented with an awareness of the population, task, and context of use, the extent to which each study showed an accurate definition of these factors varied.

A total of 21 studies used the feedback provided by users and/or stakeholders to guide their design. The user's experience was addressed holistically within the design process in 17 studies. It must be noted that the extent to which the user's experience was addressed holistically within the design of a GS-based system was difficult to extract and was not always explicit within the results. The design process was iterative in 15 studies.

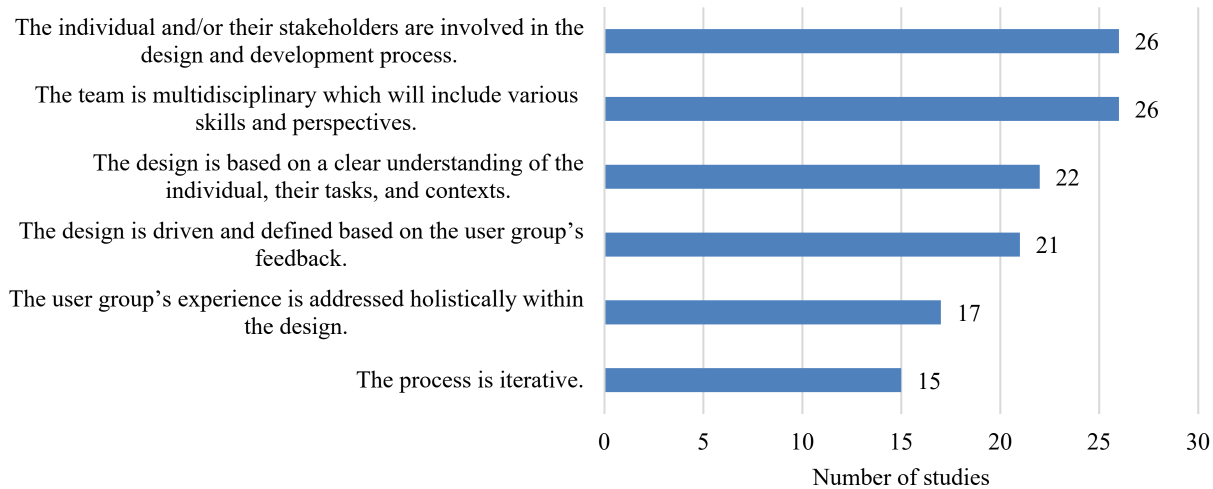

Figure 4. The six HCD principles considered in the design process.

4.4 Input obtained

The aim of this section is to identify the type of input obtained before and during the design process, based on the components of the HAAT model. The method in which information was obtained, as well as the way in which the input was used to inform decision-making, and the design process are also reported. 'Input' did not include information gathered as part of the final product evaluation.

4.4.1 Content obtained based on the components of the HAAT model

The purpose of this section was to summarise information reported in the studies regarding the population for whom the product was designed, the task that the product should help users accomplish, and the context in which the product would be used by the target population (Cook et al., 2019).

4.4.1.1 Population

The number of studies in which the population's age group, their diagnosis and their culture and/or language was considered is presented in Table 6.

Table 6

A Summary of the Results Pertaining to the Population for whom the GS-based AAC Systems are Designed

<table>
<tr><th>Population</th><th>Figure</th></tr>
<tr><td>

Age of target population

Figure 5 shows the various age groups for whom the products were designed. Many studies reported that the system designed was intended for children (*n* = 12). Few AAC systems were designed for adults (*n* = 5), while only one study reported on designing a system for both children and adults as beneficiaries of their product. It is evident that many studies (*n* = 10) did not define the intended population age, often stating the target population as 'individuals/persons with complex communication needs'.

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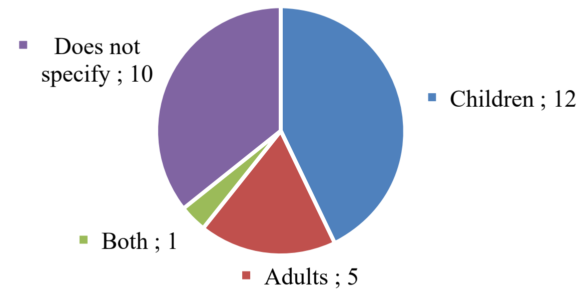

Figure 5. The population age group for whom the product is designed.

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Diagnoses and/or communication challenges of target population

The diagnoses and/or functional limitations of the target population were commonly reported. As seen in Figure 6, many studies (*n* = 10) reported on persons with complex communication needs in general, and thus did not discuss any specific diagnoses. The other studies (*n* = 18) reported on specific diagnoses that result in complex communication needs. Within these 18 studies, 13 studies discussed designing systems for persons with one specific diagnosis such as ASD (*n* = 5), aphasia (*n* = 4), CP (*n* = 3), and Down Syndrome (*n* = 1). The other five studies reported multiple diagnoses. Al-Arifi et al. (2013) reported on individuals with ASD and aphasia, Allen (2005) mainly discussed individuals with CP but also included individuals with serious head injury and degenerative diseases such as motor neurone disease. In addition, Bhattacharya and Basu (2009) considered individuals with CP, ataxia and multiple sclerosis, whereas Hayes et al. (2010) reported on individuals with ASD as their main focus but also considered other developmental disorders. Lastly, Martin et al. (2019) mainly focused on individuals with ASD but also included individuals with intellectual disabilities, Down Syndrome and attention

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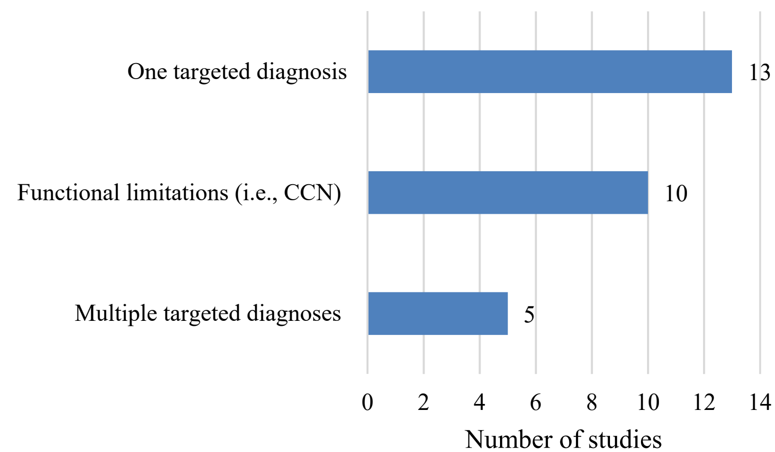
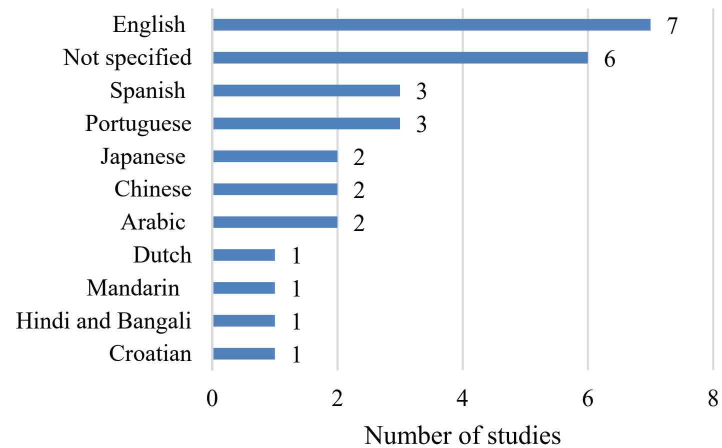


Figure 6. The diagnoses and/or functional limitations of the target population.

</td></tr>
</table>

Population	Figure
deficit hyperactivity disorder.	
Language and/or culture of the target population The languages of the target population varied quite significantly. It is evident in Figure 7 that English was reported most frequently as the language for communication (*n* = 7). Spanish (*n* = 3) and Portuguese (*n* = 3) were the next most common languages used by the target population. Japanese (*n* = 2), Chinese (*n* = 2), and Arabic (*n* = 2) were included within some of the studies as the language used for communication. Only one study each reported on Dutch (*n* = 1), Mandarin (*n* = 1), Hindi and Bengali (*n* = 1), and Croatian (*n* = 1) as languages used by the target population. Six studies did not specify the language of use. Most articles did not discuss much about the population's culture.	 *Figure 7*. Language spoken by the target population.

4.4.1.2 Task

Data was extracted on the tasks that the system was designed to help the user accomplish. Participation in conversation was reported by seven studies and included specific tasks such as improving the rate of communication during conversation (Bhattacharya & Basu, 2009; Hine et al., 2003) and increasing the individual's motivation to participate in conversations (Saturno et al., 2015). Additional, more specific tasks such as independent communication (*n* = 2), storytelling (*n* = 2), basic communication such as requesting (*n* = 2) and supporting communication and literacy tasks (*n* = 1) were also discussed by various authors. Two articles did not report on the intended task to be accomplished, while 12 studies did not specify a specific task but rather reported on improving overall face-to-face communication skills. For example, Rodríguez-Sedano et al. (2017) focused on improving overall communication and use of language.

4.4.1.3 Context

The aim of this section was to obtain information on whether the authors reported on the contexts in which their systems were to be used, and, if so, which contexts were considered. Figure 8 shows that many of the studies considered multiple contexts of use (*n* = 12), in recognition of the fact that most users need to communicate with their system in multiple contexts within their day-to-day life. Four studies focused on an educational environment. Other studies considered two environments such as home and classroom environments (*n* = 3), and home and rehabilitation centres (*n* = 1). Eight studies were not specific about the context in which the GS-based system would be used.

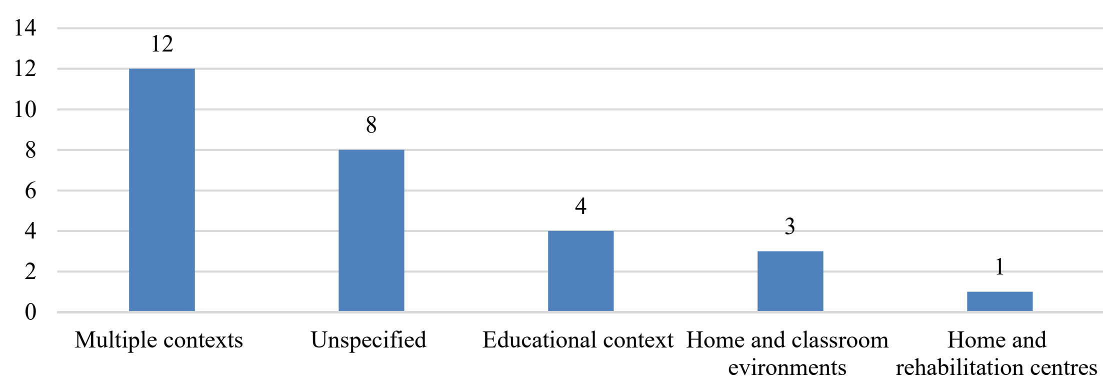


Figure 8. The context in which the AAC system is intended to be used.

4.4.2 Method in which input was obtained

Methods in which input was obtained focused on how the researchers gained information throughout the initial information gathering and prototyping stages of the design process (Tosi, 2020). The information extracted from the studies pertained to the methods used to gain input and/or feedback from persons involved within the design, whether it be the individual and/or their respective stakeholders or any additional person, such as a software designer.

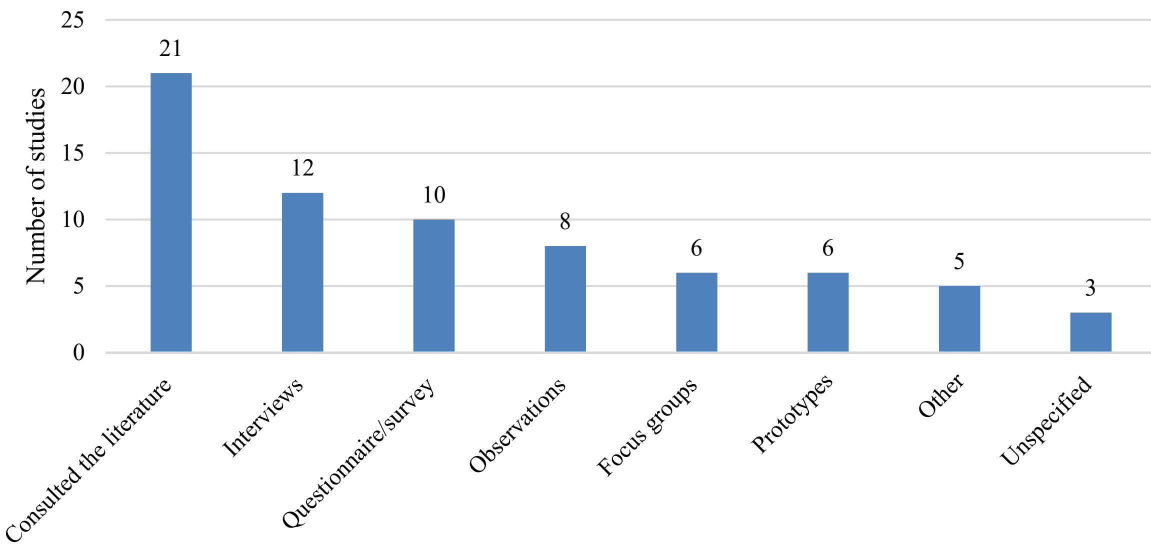


Figure 9. The methods in which input was obtained.

Figure 9 shows the various methods used to gather information. Many studies (n = 19) used more than one method to gain input. The majority of the studies (n = 21) consulted the literature to guide their AAC system design. Interviews and questionnaires/surveys were used by 12 and 10 studies respectively. Fewer studies made use of observations (n = 8) and focus groups (n = 6) to guide their design. Three studies used prototypes to gain information. Prototypes were used in various ways, for example, Allen (2005) and Al-Arifi et al. (2013) used low-fidelity prototypes (e.g., sketches) to illustrate their intended GS-based AAC system design and used these low-fidelity prototypes to gain information on either the design requirements and/or the intended populations' thoughts and preferences for the design of the system. Stančić et al. (2013) asked participants to rate nine prototypes of digital GS designs.

Three articles did not specify the method in which they obtained information but rather wrote broad statements such as "requirements were elicited with Abruzzo Regional Reference Center for Autism (CRAA) people" (Di Mascio et al., 2019, p. 4). Additional methods such as storyboards (Williams et al., 2015), cognitive walkthroughs (Al-Arifi et al., 2013), meetings (Cheung et al., 2014), workgroups (Martin et al., 2019), and monitoring trials (Karita, 2017) to gain input were used to guide the design of a GS-based AAC system.

4.5 Persons' involvement within the design process

The purpose of this section is to determine whom the authors consulted throughout the design process. The information gathered in this section is specific to the additional persons involved in the design process, as well as the person for whom it is designed, and/or their stakeholders. Therefore, this excludes the author/s, whose disciplinary or institutional affiliations were discussed in Section 4.1.

4.5.1 Additional persons' involvement

Additional designers and manufacturers were included in seven studies. Few studies reported consulting linguists (n = 3) and additional computer scientists (n = 2) during the design process. Other persons of various other designations were reported in 10 studies, such as, typically developing individuals with no relation to the target population (e.g., non-aphasic adults or children without speech or language impairments at mainstream schools) (n = 2), visual designer or art illustrator (n = 2), experts in the area of CCN (n = 1), facility staff members (n = 1), assistive technology specialists (n = 1), software designer (n = 1), persons from a medical volunteer service (n = 1), as well as engineers (n = 1).

4.5.2 User and stakeholder involvement

Stakeholders and users were involved in all of the studies. It must be acknowledged that the individuals included within each study varied and although each user/stakeholder group will be discussed separately, many studies (n = 20) consulted more than one group. For example, Babic et al. (2015) involved the user, caregivers, educators and healthcare professionals within the design process. A total of 11 studies only involved either one stakeholder or one stakeholder group. For example, Jafri et al. (2020) only included the SLT as a stakeholder, whereas Karita

(2017) included teachers as a stakeholder group.

Figure 10 shows that the individual (user) for whom the product is intended was involved in 20 studies. Stakeholders included health professionals (*n* = 19), parents/caregivers (*n* = 11), educators (*n* = 10), family members (*n* = 2), and one study included the users' peers within the design process. Health professionals varied and included persons such as SLTs (*n* = 12), occupational therapists (*n* = 5) and psychologists (*n* = 6).

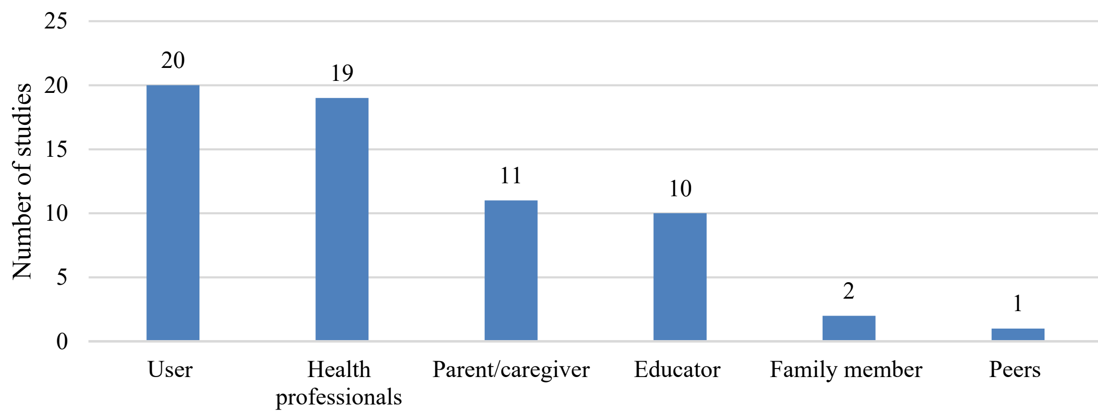


Figure 10. The user and/or stakeholder(s) involved within the design process.

It must be acknowledged that although many of these individuals were involved within each study, their roles differed. This extends to when and how they were consulted within the design process. Table 7 provides an overview of the results pertaining to the role of the users and stakeholders, the stage in which they were involved and how they were involved. Thereafter, the reasons for limited user/stakeholder involvement, if there were any, will be discussed.

Table 7

An Overview of the Information Pertaining to the User and/or Stakeholder Involvement Throughout the Design Process

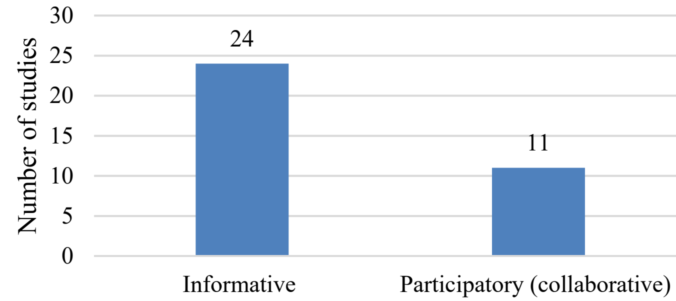
<table>
<tr><th>Description of user and/or stakeholder involvement</th><th>Figure</th></tr>
<tr><td>Role of the user and/or stakeholders involved
Figure 11 demonstrates the role of the user and/or stakeholders within the design process. The user and/or stakeholder roles may have overlapped within a study, therefore one person may have played an informative role while another a participatory role, as seen in seven studies such as Boyd-Graber et al. (2006), de Faria Borges et al. (2014) and Mahmud et al. (2013). With this said, the primary role of the users/stakeholders who were included within the design process was an informative one (n = 25). This means that they were consulted for information purposes only. Fewer studies (n = 12) reported actively involving users/stakeholders in a collaborative role within the design process.</td><td>

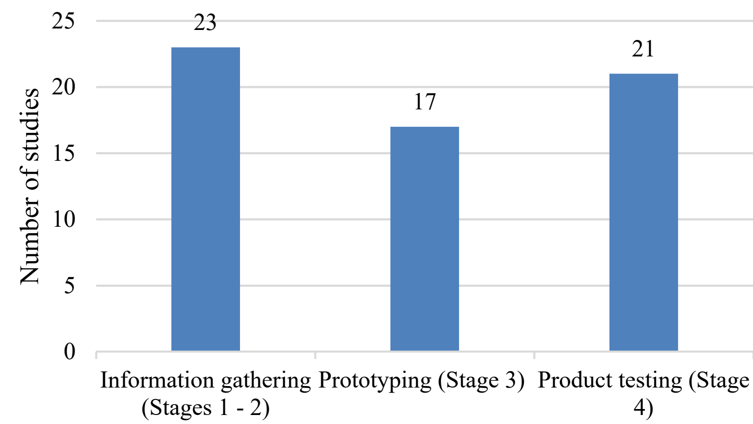
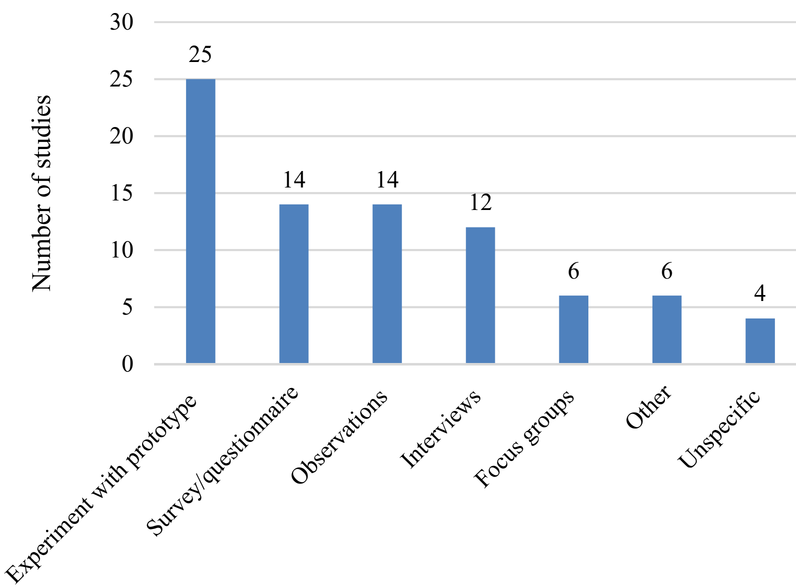
Figure 11. The user and/or stakeholders’ role within the design process.</td></tr>
<tr><td>Stages in which the user and/or stakeholders were involved
The stages of a design process were taken from Tosi's (2020) classification of the HCD process and were categorised as (a) the initial information gathering stages of the design process; (b) designing and assessing solutions (i.e., prototyping); and (c) the final product testing. The majority of the studies involved a different user/stakeholder per stage and as such no uniformity was noted. For example: Mahmud et al. (2013) gained information from SLT and individuals with aphasia (user) in the initial stages and prototyping stages but involved non-aphasic individuals to evaluate the product/high fidelity prototype. Allen (2005) consulted the same set of individuals throughout the design process, that is, adults with speech and language impairments (users). Figure 12 indicates that the users and/or stakeholders were commonly consulted within the initial, information gathering stages of the design process (n = 23), as well as during the final product/prototyping testing (n = 21). Fewer users/stakeholders (n = 17) were involved during the third, prototyping stage.</td><td>

Figure 12. The stages in which the user and/or stakeholder(s) are involved within the design process.</td></tr>
</table>

Description of user and/or stakeholder involvement	Figure
Obtaining information from user and/or stakeholders The information displayed in Figure 13 is based on the information gathering methods, as well as evaluation methods used to gather input or obtain feedback from the individual and/or their stakeholders (Tao et al., 2020; Tosi, 2020). Therefore, this section covers methods used during all four stages of the design process. Experimenting with prototypes was reported in 25 studies and was used to either gain user and/or stakeholder input earlier in the design process or during the evaluation of the final prototype or product. The use of questionnaires or surveys was reported in 14 studies. Observations (*n* = 14) and interviews (*n* = 12) were also common methods used to gain user/stakeholder input. Fewer studies, six to be exact, used focus groups to receive stakeholder input. Four studies did not specify the way in which stakeholders' input was received. Six studies discussed other methods such as using user acceptance tests (Cheung et al., 2014), consultations or meetings (Boyd-Graber et al., 2006), monitoring trials and scenarios. An et al. (2017) reported the use of the Vineland Adaptive Behaviour Scale and Aberrant Behaviour Checklist to evaluate user competencies, and thus this method of input did not entail active engagement from the users.	 *Figure 13.* The types of methods used to obtain information from the user and/or stakeholders.

4.5.3 Reason for limited or no involvement from users and/or stakeholders

The majority of studies (*n* = 15) did not report any reasons for limited or no involvement of the individual and/or their stakeholders. For the most part, this is because the individual/stakeholders were often included within the design process. The most commonly reported limitation in these studies was the fact that persons with CCN may not be able to express their opinions or ideas and thus it is usually difficult to engage such persons within a design process (Lubas et al., 2014; Mahmud et al., 2013). Babic et al. (2015) discussed time constraints as a reason for limited user participation. Rodríguez-Sedano et al. (2017) discussed ethical considerations, such as receiving consent from parents. Financial constraints were not reported by any of the studies.

4.6 Product evaluation and outcomes

The evaluation of the product designed will be summarised by describing the constructs evaluated and the methods in which the product was evaluated, the outcomes of said evaluations, and the availability of the product. The outcomes of the studies were not always final products available to the public, but also included prototypes that were at the final stage of the development process. Information on the methods used to evaluate the prototypes at the final stage of the development process is reported here and does not overlap with the information provided in Section 4.4.2, where the methods to obtain input before and during the design process are reported.

4.6.1 Constructs evaluated

Figure 14 indicates that the usability of the system, that is, its overall efficiency and effectiveness of use (Tosi, 2020), was the construct most frequently evaluated and reported by 22 studies. Twelve studies each evaluated the ease of use of a system and the system's functional performance. The individual's ability to perform a task or participate using the final AAC system was specifically evaluated in nine studies. Five studies evaluated the person's acceptance of the designed system, but few reported on how the system can affect quality of life (*n* = 3).

Five studies evaluated additional constructs such as accessibility (*n* = 4), which addresses how easily an individual can access the system and the features designed (Williams et al., 2015), and one study focusing on the feasibility (practicability) of including system features within the design (Hill, 2006).

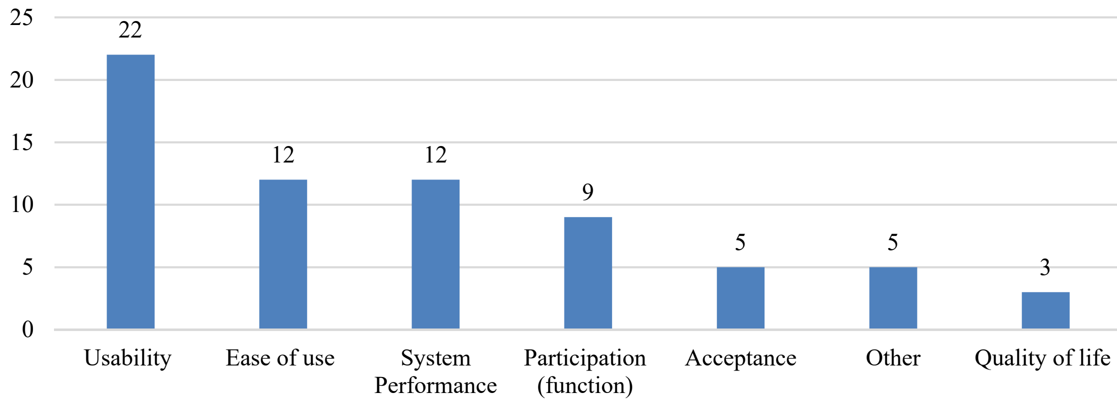


Figure 14. The system characteristics and system effects evaluated.

4.6.2 Methods used in the evaluation process

Figure 15 shows that experience prototyping was used most often as an evaluation tool (*n* = 25). The next commonly used method to evaluate the final product or prototype was the use of a questionnaire or survey (*n* = 15). Examples of the surveys used included the SUS (Al-Arifi et al., 2013), a web-based survey after purchase and use of the product (Lubas et al., 2014), and oral surveys as seen in Martin et al. (2019). Scenarios such as role playing, creating personas and fitting test scenarios were used in 10 studies. Observations (*n* = 10) were used more than focus groups (*n* = 4), interviews (*n* = 3) and applied ethnography (*n* = 3).

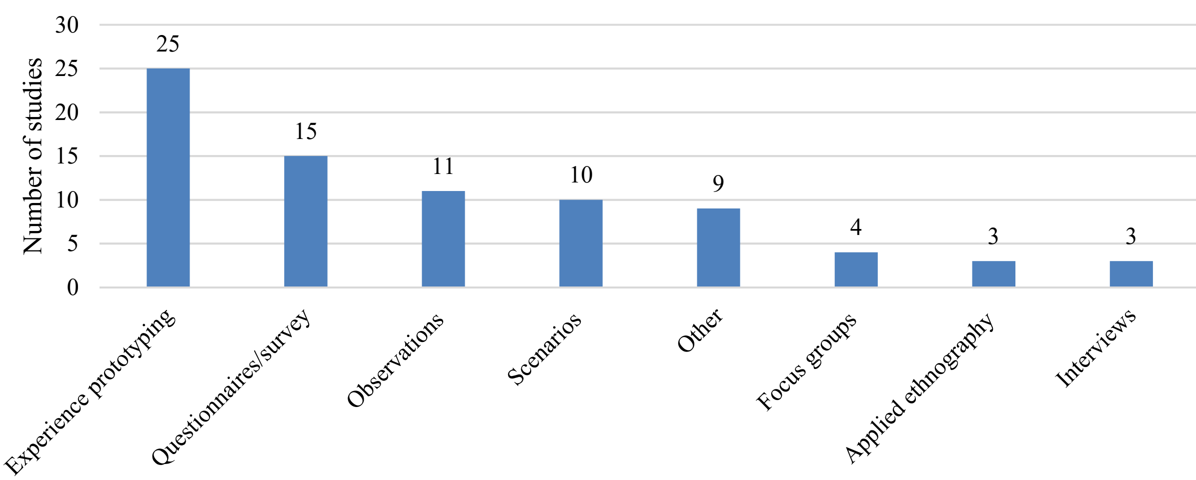


Figure 15. The methods used to evaluate the final product.

Many studies (*n* = 9) discussed the use of other methods to evaluate their products. These included: a collection of performance data or logs (*n* = 2), interactions with parents and teachers (*n* = 1), software testing (*n* = 1), expert-based usability tests (*n* = 1), consultations (*n* = 1), analysis of video recordings (*n* = 2), and user acceptance tests (*n* = 1).

4.6.3 Outcomes of evaluation

The outcomes of the products evaluated are displayed in Figure 16. Of the products developed, 14 met the requirements set out by the researchers, whereas 13 products partially met the targeted requirements. There was no indication from the studies that any of the products did not meet the targeted requirements. Mendes and Correia (2013) did not specify the outcome of their designed AAC system; however, they did report the need for adjustments to their system design.

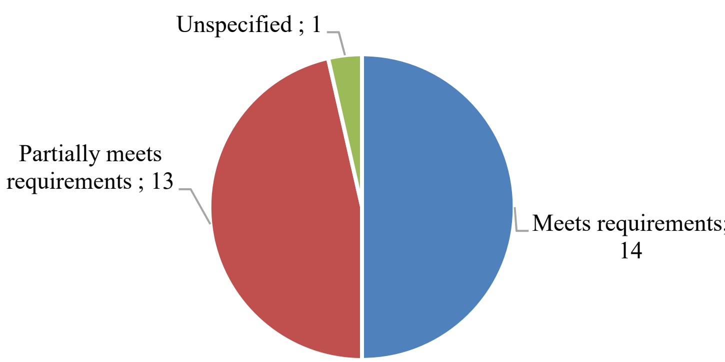


Figure 16. The evaluation outcomes of the designed product.

The need to redesign or adjust the products/prototypes designed was reported in eight studies. For example, Karita (2017) suggested improvements regarding the user interface and the product usability. Mahmud et al. (2013) were more specific and reported on implementing an overview page such as a calendar in the design interface, as well as addressing the number of pictures in a cluster and the ability to delete and edit pictures. Williams et al., (2015) reported on refining the input mechanism and vocabulary structure of the system designed.

4.6.4 Availability of the product

The availability of the products and/or prototypes designed was not commonly reported. 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 (2018) reported that their product was available but did not specify whether the product was freely or commercially available, whereas Bhattacharya and Basu (2009) stated that the product was deployed at a number of institutions but did not specify if this product was also available for the public.

4.7 Limitations and future recommendations

4.7.1 Constraints experienced in the design process as reported by authors

Figure 17 shows that most studies did not report any constraints or limitations to their design process (n = 14). The limited number of participants/sample size was reported in five studies.

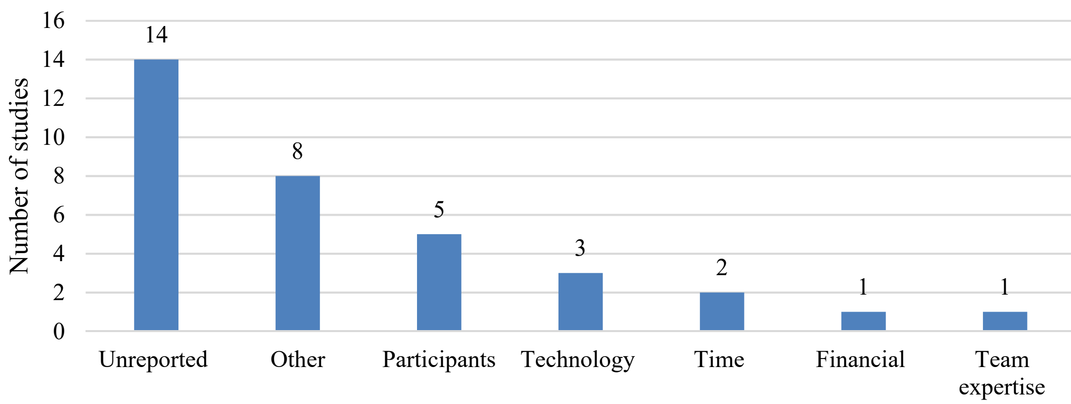


Figure 17. Constraints experienced in the design process.

A total of eight studies discussed other constraints. These constraints included aspects such as only considering a limited range of communication needs and settings (Hirotomi, 2018) and thus being unable to ensure generalisability of the results. Challenges with the interpretation of interview feedback from persons with aphasia, as well as having no control conditions (Williams et al., 2015) and limited user feedback from the individual(s) using the system after purchasing the system were also reported (Lubas et al., 2014). Jafri et al.'s (2020) study was halted due to the COVID-19 pandemic and as a result, the evaluation process could not take place. Furthermore, the challenges of having to coordinate the persons' roles within a multidisciplinary context (Di Mascio et al., 2019), and the effects of the quality and efficacy of the results provided by persons with CCN (Allen, 2005), were also discussed.

Three studies discussed more than one constraint. Allen (2005) discussed time and financial constraints and Boyd-Graber et al. (2006) mentioned both time and technological limitations. Allen (2005) was the only author to report team expertise as a constraint, stating that many AAC users lack coordinated motor control and thus, the possibility of using non-verbal media such as sketching to represent their ideas was limited.

4.7.2 Recommendations

Figure 18 demonstrates the future recommendations reported by the researchers. It is evident from the figure below that the majority of the studies reported the need for future research (n = 21) and development (n = 15). A total of 11 of the 28 studies included the need for both future research and development. For instance, de Oliveira et al. (2016) reported the need to develop and adapt VoxLaps "to recognize Bluetooth devices in order to expand the target audience that can be benefited" (p. 139) and thus tests with patients are currently being conducted. In addition, Hervás et al. (2020) reported the need to improve both prediction results and the prediction-based mechanisms within the system design.

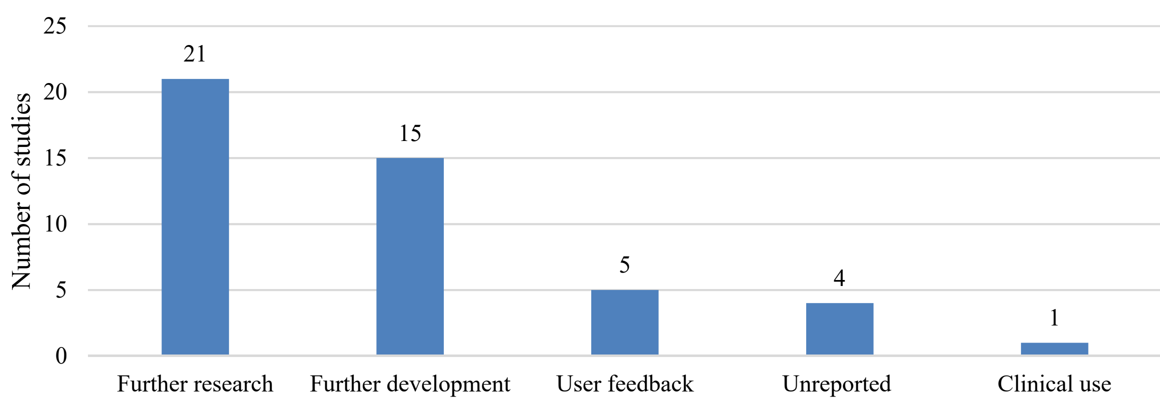


Figure 18. Recommendations reported by the authors.

The need for user feedback was reported in five studies. For example, Hervás et al. (2020) reported the need to validate the product with end users via the use of questionnaires. Future work regarding the clinical use of the system was reported in one study. Only four studies did not report any future recommendations.

5 DISCUSSION

The purpose of this section is to discuss the data extracted and summarised from the 28 design studies identified within this review in relation to the literature. First, the characteristics of the studies identified as well as the GS-based AAC features designed will be explored. Thereafter, a discussion on the design approaches and principles used, the input obtained, as well as the persons involved within the design process will follow. Lastly, the product evaluations and outcomes, and the limitations and future recommendations, will be discussed.

5.1 Characteristics of the studies identified within this review

5.1.1 Number of publications

This study revealed that most of the publications reporting the design of GS-based AAC systems were noted within the last 10 years. Interestingly, this study revealed that the devices in which a GS-based AAC system operates have also evolved between 2000 and 2020, with more GS-based AAC systems being designed as applications for mobile technology, rather than for devices such as PDAs and PCs. This could be due to the fact that recent advances in mobile technology and the wide market for AAC system development have caused a surge in designing AAC applications for mobile technology (Al-Arifi et al., 2013; McNaughton & Light, 2013).

According to Gosnell et al. (2011), there were over 110 communication applications available for download onto iOS-based hardware in 2011 alone. Call Scotland (2020), a research and development centre and service unit for children with disabilities and learning barriers, has also provided data showing some of the popular Android[5]- and iPad[6]-based AAC applications for persons with CCN, which indicate 45 and 68 applications respectively. While it must be kept in mind that this information is not a true reflection of all the available AAC applications, it may provide a good indication of the types and number of AAC applications available.

Despite the increased number of communication systems/applications being developed by both prominent and lesser known AAC technology developers, only 28 studies discussing the full design process of electronic GS-based AAC systems were identified. There may be several reasons for this, such as the design process not being documented in academic literature, while being documented elsewhere but not accessible to the public, with such information possibly

[5] Updated 2018.
[6] Updated 2020.

protected under patents and intellectual property law (Almoaiqel et al., 2020). It is also possible that design processes are multifaceted and complex (Moggridge, 2007; Steen, 2011), and that they are reported in numerous papers and studies, which may have been excluded from the review as they individually may not have met all the inclusion criteria. In addition, possible limitations of databases searched and the identified search terms must be acknowledged.

5.1.2 Authors' disciplinary and/or institutional affiliation

Computer science and engineering are two dominating disciplines in the field of designing AT technology (Gregor & Hevner, 2013). As AAC systems fall under this domain, it is no surprise that many of the authors within this study are affiliated to these disciplines (Dunst et al., 2013). According to McNaughton & Light (2013), AAC research and development now includes a wider range of stakeholders (as researchers/developers) in a field which was previously restricted to traditional AT manufacturers. However, the limited number of authors from AAC and/or communication-related disciplines within the research team suggests otherwise.

AAC professionals, such as SLTs, have a crucial role in the assessment, selection and implementation of AAC services (Dada, Murphy, et al., 2017), and as such, it would be desirable to have such professionals as authors, at the forefront of GS-based AAC system design research and development, along with other institutional disciplines such as computer science, engineering, and/or education (Gregor & Hevner, 2013; Pullin et al., 2017). However, it must be acknowledged that possible barriers such as professional boundaries within research may influence the role of certain disciplines within the research and development of GS-based AAC systems.

5.1.3 Country in which the study took place

This review found that many of the studies were conducted in European countries, with fewer reported in North America. This is interesting as one would expect a similar number of studies based in European and North American countries, given that the majority of research and development of AAC technology is conducted in such high-income countries (Tönsing et al., 2019). According to Sanders et al. (2006), this may be due to American designers and design researchers (predominantly practitioners) having been found to be less willing to disseminate knowledge amongst peer researchers regarding design research in practice. In contrast, European design researchers (mostly academics) have a more transparent approach to reporting design processes (as is tradition in academia), and thus are leading in sharing and disseminating knowledge about design research in practice (Sanders et al., 2006). This may explain the increased number of studies based in European countries.

Soto and Yu (2014) have highlighted the increase in the development of indigenous AAC systems in many countries, with specific attention on China and India. Much like Soto and Yu's (2014) observations, this review has found an increase of reported GS-based AAC systems designed in Asian countries, which not only included China and India but additional countries such as Japan, Korea and Saudi Arabia. In addition, GS-based AAC systems designed in Brazil were also reported. This is promising as existing studies have highlighted the need for GS-based AAC systems that can accommodate local cultures and languages other than English (Al-Arifi et al., 2013; Bhattacharya & Basu, 2009). Unfortunately, none of the studies were based in African countries and as such, further research and development is required to address this gap in GS-based AAC system research design.

5.2 Description of the AAC system features

This review has demonstrated the popularity of designing GS-based systems/applications for mobile technology. While some studies did not report on the reasons for selecting such systems, Dada, Murphy et al. (2017) and McNaughton and Light (2013) suggest that the increase in the availability of mobile technology, with the loaded AAC systems/applications, have made these systems a common choice. In addition, not only is mobile technology more affordable, it is reportedly easy to use, easily accessed, functional and supports interconnectivity (Dada, Murphy, et al., 2017; McNaughton & Light, 2013). Furthermore, the maintenance of the hardware of mobile technology is significantly cheaper in contrast to dedicated systems that require parts to be internationally sourced, which can become a complex and expensive process (Dada, Murphy et al., 2017).

Moreover, there is less stigma associated with using mainstream technology as hardware, since it is used by many people, with or without CCN, and because of the overall aesthetic appeal of the device (Boster & McCarthy, 2018; Dada, Murphy, et al., 2017; Ogletree et al., 2018). In addition, the smaller size and lighter weight (i.e., portability) of these devices make them easy to transport between contexts (Hine et al., 2003). Portability is a crucial element that can influence the acceptance of a device (Light & Drager, 2002; Murray et al., 2019). Even though few studies pertinently reported on the portability and aesthetic appeal of the device, these factors generally rate highly when it comes to mobile technology (Light & Drager, 2002).

Despite the many advantages of designing GS-based AAC systems for mobile technology, there are still some potential challenges to its application (McNaughton & Light, 2013). For instance, the proliferation of new, available AAC systems has shifted focus from service-driven delivery to that of consumer-driven delivery in which individuals do not have to consult with an AAC professional before purchasing an application (McNaughton & Light, 2013). While this shift in delivery democratises access to such systems, simply providing access to GS-based AAC systems, without ensuring the system suits persons specific needs, does not ensure effective communication (McNaughton & Light, 2013).

Furthermore, this review has demonstrated that many studies reported on the design of a GS-based AAC system with a dynamic display. This is in accordance with the literature, as non-dedicated GS-based AAC systems typically capitalise on the dynamic screen possibilities of the hardware, and display GS on a multiple (dynamic) page layout, rather than on one (static) page layout in order to facilitate a large vocabulary for expressive power (Judge et al., 2019). It must be acknowledged that although dynamic GS-based AAC systems have an advantage in that the inclusion of more vocabulary can facilitate language development and further support social interaction, the larger vocabulary increases cognitive demands, as persons with CCN need to search multiple pages and/or take several steps to navigate the target GS (Tenny, 2016). However, when each vocabulary item is accessed with a consistent motor plan, motor automaticity can develop, resulting in greater ease of GS selection and a faster rate of communication (Dukhovny & Gahl, 2014; Tenny, 2016).

This review also revealed that the GS in the designed systems were mainly arranged in a grid display. According to Judge et al. (2019) and Light et al. (2019), this is not unusual, as many GS-based systems are structured based on older low-tech/paper-based systems, which typically consisted of grid-based displays. Unfortunately, following such an approach may not always demonstrate the latest research evidence and thus there is minimal evidence proving its appropriateness and/or effectiveness for the target population (Light et al., 2004; McNaughton & Light, 2013).

Moreover, despite increased literature on VSDs and their potential benefits for early communicators (Light et al., 2019; Reichle & Drager, 2010), few studies made use of this feature in this review. This may be due to multiple reasons. First, as VSDs are better suited for early communicators, it may not have been appropriate for the age and level of functioning of the population for whom the systems were designed (Light, Wilkinson, et al., 2019). Second, although VSDs can provide more context-specific language within a scene layout, they do not always consider that vocabulary could be used across various contexts and thus may influence the individual's ability to generalise such vocabulary (Light et al., 2004; von Tetzchner, 2015).

It is evident from this review that most studies included GS from existing AAC GS libraries. In accordance with other studies, some GS-based AAC systems within this review included PCS and Widgit symbol libraries (Dada, Murphy, et al., 2017; Tönsing et al., 2019). Interestingly, the Aragonese Portal of AAC (ARASAAC)[7] library was used more often. While many studies did not explicitly state the reason for using such GS-based libraries, Silva et al. (2018) selected the ARASAAC symbols because they are freely available and thus easily accessible. This correlates to one of the trade-offs and considerations designers need to make when selecting the appropriate GS library, as discussed in Section 1.4.1.4 (Pampoulou, 2017).

In addition to GS libraries, many of the studies included a feature that allowed users to capture and download photographs, and to incorporate them into the GS-based AAC system. This is congruent with the literature, as Light, Wilkinson et al. (2019) highlighted that taking pictures and capturing meaningful daily events has been made easier due to cameras being available on mobile technology.

Moreover, colour-coding GS was reported in some studies. This is a promising result as the colour of symbols and background plays a large 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 (Thistle & Wilkinson, 2015). 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 (Thistle & Wilkinson, 2015).

In addition, the availability and type of vocabulary is a factor that requires much consideration (Dada, Murphy, et al., 2017). This review found that few studies considered the

[7] ARASAAC is a product of the Aragonese Centre of Technologies for Education (CATEDU), Zaragoza, Spain, https://arasaac.org/.

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. This review also revealed that many studies allowed voice output to be personalised in that individuals could choose the type of voice output recorded to match the vocabulary added to the system. This is a desirable approach given that greater flexibility in the type of vocabulary and voice output used can allow users and stakeholders to personalise the system. Personalised AAC systems can better accommodate and reflect each individual's desires, preferences, culture and linguistic background (Di Mascio et al., 2019; Jafri et al., 2020; Valencia et al., 2020).

Furthermore, most studies reported a touch screen as an access feature (e.g., the indidivual can select the relevant GS by touching the screen of the device). This is in accordance with An et al. (2017), who found that 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 would expect to find more studies considering these additional access features (Beukelman & Light, 2020; Murray et al., 2019).

5.3 Design approaches and principles

Although the HCD framework has been a suggested desirable approach in the design of AT devices (Sanders & Stappers, 2008; Waller et al., 2005), the use of HCD approaches by those studies considered within this review was rarely reported. Furthermore, there were many studies which simply did not report the design approach that guided their decision-making and the design process which was utilised. With the majority of studies not including HCD within their design approach, it is unclear whether HCD remains an emerging area in GS-based AAC system development, or whether it is not considered appropriate by designers. Reasons or the latter may include the challenges surrounding the involvement of the heterogenous target population with CCN or due to there being limited literature concerning the use of HCD for persons with CCN (Pullin et al., 2017).

Despite the several HCD approaches available to designers (Sanders & Stappers, 2008), the participatory design approach was the only specific HCD reported within this review. De Faria Borges et al. (2014) highlighted that a participatory design approach is commonly used and frequently regarded as a convenient approach to AT system design for persons with CCN, and as such it is no surprise that such an approach was the one specific HCD approach reported. However, given its reported popularity, it would be expected that more studies would use a participatory design approach to guide their system design. The lack of use may be because this approach demands active participation from the target population who can easily or clearly express their needs, wants and desires (de Faria Borges et al., 2014). This may be particularly difficult when designing systems for a diverse group of individuals with CCN, especially when most systems may need to involve children with disabilities (Benton & Johnson, 2015).

In addition, the way in which the participatory design approach was reported in terms of terminology, methods and the degree to which this approach was used (in those studies which had utilised the approach) varied between the studies within this review. This coincides with Spinuzzi's (2005) view that the rigour and validity in terms of the implementation of a participatory design approach varies among the literature, which may be a result of the approach undergoing multiple changes over the course of the last decade. Despite the variation in terminology and the differences regarding the methods used to gain information and evaluate the product, each study that used the participatory design approach to guide their system design complied with the six HCD principles. This is also consistent with Spinuzzi's (2005) view that despite the changes and differences in the participatory design methods and terminology used, the core of this approach remains consistent.

Although there has been a move away from the use of a UCD (Sanders & Stappers, 2008; Tosi, 2020), this review demonstrated that many studies still follow this approach within GS-based AAC system design, and more so than HCD approaches. This may be due to many reasons, for instance, UCD and HCD approaches are often reported interchangeably within the literature, and, as a result, many designers and researchers may mistake these two components as the same approach (Sanders & Stappers, 2008; Steen, 2011).

In addition, HCD is said to have evolved from UCD and thus there are many similarities in the design processes and methods used. However, the key difference is the role of the individual and/or their stakeholder within the design process (Brischetto, 2020). Therefore, the decision to use a UCD approach may be because it is easier to involve users within the design process as subjects (i.e., as sources of information), whereby designers tend to focus on including users during the evaluation stages with little involvement at the early stages of design (Waller et al., 2005). This differs from an HCD as individuals are seen as “holders of experience” and are thus involved in a collaborative manner throughout the design process, particularly during the earlier stages of the design process (Brischetto, 2020, p. 48).

As found in this review, the problem with using a UCD approach is that without user feedback throughout the design process, the designer may not gain an accurate understanding of the user’s requirements, and consequently the user’s experience cannot be holistically incorporated or defined within the design requirements of the intended product (Marti & Bannon, 2009). As a result, many of the studies reporting the use of UCD did not comply with all six HCD principles.

Despite some studies reporting on the use of alternative or mixed research design approaches, they still complied with the six HCD principles. Interestingly, these studies made mention of a HCD or UCD, but did not explicitly report that they used these approaches to guide their design process. Steen (2011) wrote that designers often follow watered-down design approaches during the design of products and thus it is possible that these studies have followed either of the aforesaid approaches but did not label it as such.

Consequently, what this study has exposed is the need to be more transparent about the type of design approach used to guide the system design, as well as clearly report on design approaches and processes used. The disadvantage of the inconsistent use of terminology and/or terminology confusion is that there may be different interpretations of such design approaches, and thus it is difficult to consolidate the literature (Steen, 2011). This may explain the eclectic approach to designing systems often adopted by designers (Steen, 2011).

It is evident from this review that there is not one single design approach that will suit all design studies, which is confirmed and reiterated by the literature (Steen, 2011). In some ways, due to the heterogenous population in need of GS-based AAC systems, having various options of design approaches may be beneficial for designers as it provides flexibility in that designers can choose a design approach and method that would be most beneficial for the optimal inclusion of the population intended for the system designed, as well as accommodate for any contextual factors relating to the design process (Steen, 2011; Wakkary, 2007). It is for this reason that the inclusion of an HCD framework and principles should be prioritised as it provides an opportunity to choose from several approaches that may facilitate the extent to which the individual and their stakeholder/s are involved within the design process based on the possible constraints designers face when designing such GS-based AAC systems (Sanders & Stappers, 2008; Steen, 2011).

5.4 Input obtained

5.4.1 Components of the HAAT model

While it is beyond the scope of this review to provide an in-depth description of all information provided regarding the population for whom each study was designed, the task to be accomplished, and the context of use, a few key insights from this review will be highlighted in the following sections.

Many studies in this review discussed the population, the task to be accomplished and the context of use in a general manner. This included broad statements such as designing systems for persons with communication and speech impairments to improve their face-to-face communication tasks within multiple day-to-day contexts (Cheung et al., 2014; de Oliveira et al., 2016; Hine et al., 2003). While this approach to identifying user requirements allows the product to accommodate for a wider range of individuals and decreases the chance of over-emphasising the findings from a small number of users (Ogletree et al., 2018; Persson et al., 2015), it does run the risk of omitting specific needs of individuals with additional or different impairments, such as a visual, cognitive or motor impairment (Dunst et al., 2013; Lubas et al., 2014; Tao et al., 2020; Waller, 2019).

4.4.1.1 Population

Although adults with CCN benefit from GS-based AAC systems (Boyd-Graber et al., 2006), often these systems are developed and used more by children (Light et al., 2009). This is consistent with the outcomes of this review as more systems were designed for children compared to adults. The reason for this age discrepancy may be due to adults with CCN usually using text-based systems rather than GS-based AAC systems to communicate (Light & Drager, 2002; Thistle & Wilkinson, 2015; Webb et al., 2019). As seen within the literature and within this review, adults who would require GS-based AAC systems often have impairments in the production and/or comprehension of verbal and written language, which is commonly associated with aphasia (Boyd-Graber et al., 2006; Daemen et al., 2007).

While the main commonality between the different age groups was the fact that each target population group had complex communication needs, their diagnoses differed. In conjunction with the literature, the specific diagnoses reported included physical disabilities such as CP, intellectual and/or developmental disabilities such as ASD and Down Syndrome, and acquired disorders such as stroke and traumatic brain injury, all of which result in CCN (Boster & McCarthy, 2018; Dada, Murphy, et al., 2017; Waller, 2019).

In spite of the prevalence of multilingual populations who have CCN, AAC development and research still primarily focus on one language for communication (Tönsing et al., 2019). This correlates to the findings in this review as the majority of the studies designed systems focusing on one main language for communication. However, an encouraging outcome from this review is that both Bhattacharya and Basu (2009) and Rodríguez-Sedano et al. (2017) considered the use of two languages within their GS-based AAC system designs. In addition, due to many studies including the customisation of vocabulary and GS (including photographs) within their systems, this can allow users to use additional languages within these systems (Rodríguez-Sedano et al., 2017). However, it is also important to keep in mind that simply adding or translating the same vocabulary or GS sets into another language is not enough to truly reflect the way in which multilingual persons with CCN can learn and use their respective languages within various contexts (Soto & Yu, 2014). Therefore, language-specific features such as word and grammar prediction may need to be incorporated into the design from the beginning rather than assuming one device can just be 'tweaked' or customised by the user to add another language (Trnka et al., 2006).

Although English was commonly reported as the language for communication, this review found that there is an increase in the design of GS-based AAC systems for additional languages such as Arabic, Croatian, Portuguese, Spanish and so forth. This is a promising outcome, as often GS-based AAC systems are structured around the English language and do not easily accommodate the use of additional languages (Light & Drager, 2002; Tönsing et al., 2020).

4.4.1.2 Task

According to the literature, GS-based AAC system research and design is often focused on facilitating requesting, labelling, and answering yes or no questions (Light et al., 2019; McNaughton & Light, 2013). As a result, commercial AAC systems rarely facilitate social interaction and engagement explicitly (Pullin et al., 2017). This may be beacuase it is easier to measure and research basic skills such as requests as opposed to measuring a broader concept such as ease of conversation (Light et al., 2019). In contrast, the findings of this review demonstrated that many studies focused on gaining independence during conversation, building social connections, and supporting language and literacy development (Allen, 2005; de Faria Borges et al., 2014; Mendes & Correia, 2013; Silva et al., 2018). For example, one study focused on designing a system to improve storytelling, thereby allowing persons with aphasia to share their daily experiences (Mahmud et al., 2013). Fewer design studies focused solely on requesting as a communication task to be accomplished (An et al., 2017; Di Mascio et al., 2019; Hill, 2006). This is an encouraging outcome in that there was an observed shift in focus from basic requesting skills to supporting independent communication, as well as language and literacy development when designing GS-based AAC systems, which has been a developing area of research (Ganz et al., 2017).

4.4.1.3 Context

The context of use was reported less often than the population and task to be accomplished. Although some studies used information regarding the user's context/environment to guide user and system requirements, such as identifying vocabulary for certain subjects in an educational environment (Saturno et al., 2015), many briefly mentioned the context of use such as a home, educational or rehabilitation environment. For adults, additional contexts such as the shops or restaurants were also reported. Designing GS-based AAC systems to suit the environment/s in which the individual will use their device is important as it can promote generalised skills learned (for children) and provide greater opportunities for communication within multiple contexts.

At a superficial level, this review demonstrated that studies rarely reported on the possible barriers and facilitators within the environment. Intuitively, this could be because accessibility and considerations of contextual factors are aspects that the hardware must accommodate for, more than the designed software noted within this study. However, designers need to be aware of this issue as one of the drawbacks (shortcomings) of solely designing the software and relying on non-dedicated hardware, which may ignore factors such as the acoustics, lighting, and the availability of a stable supporting surface for the device, which may influence the effectiveness of the system (Light, McNaughton, et al., 2019; Van Niekerk & Tönsing, 2015). These are important factors to consider, as a noisy environment or the inability to see the screen due to poor lighting may hinder the individual's ability to perform a task within any given context (Light, McNaughton, et al., 2019).

It is evident from this review that even though none of the studies explicitly reported on the use of the HAAT/CAT model, the majority of the studies reported, perhaps unknowingly, on its components, namely the population group, the task to be accomplished and the context in which the system will be used by the relevant population. However, a general observation from this review was the varying degrees to which each study discussed these components. Further research is required to explore the extent to which the information gathered regarding the HAAT/CAT components influences the decisions made in design studies for a GS-based AAC system.

5.4.2 Method in which input was obtained

The most reported method used to gain information on both the user and the system's requirements was consulting the literature, which included database searches or reviewing literature based on older designs or related work that can guide decision-making and define user and/or system requirements (Hervás et al., 2020; Hill, 2006). While it is good to build on what has been done before in AAC system design, uncritical adoption of previous models runs the risk of the continual use of particular techniques that have almost become tradition, instead of adopting or acknowledging the latest scientific evidence (Green, 2008; Smith, 2016). This has implications for the design of GS-based AAC systems, as systems may be designed based on what was technologically possible and what was known in the 1980s, rather than on latest evidence and technology possibilities (McNaughton & Light, 2013).

In combination with consulting the literature, many studies within this review made use of interviews and questionnaires or surveys. This is consistent with the literature, as Tao et al. (2020) also found that interviews were a commonly used method to gain input in AT system design. Fewer studies reported on the use of focus groups and observations early within the design process. This contrasts with the literature, as focus groups and observations have been reported to be used more often to gain user and/or design requirements in AT system design (Black et al., 2012; Marti & Bannon, 2009; Waller et al., 2005).

While few designers reported on the reason for selecting certain information gathering methods, possible reasons for the use of questionnaire/surveys and interviews, as opposed to a focus group, is that these methods are easy to use, structured, and typically require short answers or choosing options for closed-ended questions (Tao et al., 2020; Tosi, 2020). They therefore require less verbal communication from the respondent (Tao et al., 2020; Tosi, 2020). In contrast, a focus group requires more active engagement, where the individual will need to clearly express their ideas and needs, which may be particularly difficult for persons with CCN (Prior et al., 2013).

Additional methods for obtaining input documented in this review, such as storyboards (Williams et al., 2015), cognitive walkthroughs (Al-Arifi et al., 2013), meetings (Cheung et al., 2014), workgroups (Martin et al., 2019), and monitoring trials (Karita, 2017) are also types of input gathering methods that can be used within an HCD process, albeit used less common than methods such as interviews (Tosi, 2020).

Moreover, this review demonstrated that many studies used more than one information gathering method within their design process. This is in accordance with Tosi (2020), who highlighted that the design process is often iterative, and consequently designers may need to either repeat, change and/or use multiple information gathering methods to gain information on the certain population and design requirements needed.

5.5 Persons' involvement within the design process

A positive outcome from this review was the inclusion of users and/or stakeholders within all of the design studies. This review found that the majority of the studies included the target population and/or their stakeholders during the initial information gathering and evaluation stages of the design process. According to Allsop et al. (2010), the inclusion of the individual and their relevant stakeholders in the early stages of the design process is a key factor in AT system design, as it can ensure that the systems designed match the individual's needs, abilities and desires, which can ultimately increase usability.

Moreover, it is common for designers to involve the target population during the evaluation stages of the design process (Waller et al., 2005). According to Choi (2011), this may be due to the fact that end-users' feedback may be more accurate and beneficial when provided with a more physical and functional representation of a design, in this case a final product or prototype, as opposed to being tasked with visualising an abstract concept of an intended product.

In addition, it is clear from the results that many studies consulted more than one stakeholder, which included the individual with CCN. In accordance with the literature, many of the stakeholders within this review included persons such as the relevant professionals (e.g., SLTs, OTs, and educators), the parents/caregivers or other family members (Babic et al., 2015; Uthoff et al., 2021). Interestingly, Hirotomi (2018) included the users' peers as stakeholders within their design. While the inclusion of multiple perspectives throughout the design process may benefit designers in gaining more information that can potentially influence the outcome of the system, collecting and incorporating this information into a single design may be challenging (Choi, 2011). Therefore, the extent to which user and/or stakeholder contributions are incorporated into the design will differ depending on the experience of the designers, as well as the design requirements (Allsop et al., 2010).

Furthermore, the extent to which each of these individuals was consulted differed significantly within this review. This review found that the majority of the users and/or stakeholders played an informative role in the design process, whereby the designers gained user and/or system requirements using techniques such as observations, questionnaires, interviews, and experience prototyping. Few studies included stakeholders in a participatory or collaborative manner. Actively engaging stakeholders within a design needs much consideration, and, although it was rarely stated in the studies reviewed, contextual factors such as time and money (Choi, 2011; Marti & Bannon, 2009) may be reasons for stakeholders playing a smaller, informative role within the design of GS-based systems.

Another reason for possibly not actively involving the user may be due to the fact that the individuals with CCN, either children and/or adults, found it difficult to clearly express their opinions or ideas and thus their feedback was difficult to interpret or conceptualise (Lubas et al., 2014; Mahmud et al., 2013). Consequently, some studies used proxies in place of the user, as seen in Boyd-Graber et al. (2006) and Mahmud et al. (2013), which is not uncommon considering the CCN of the individuals (Light et al., 2007). As discussed in Section 2.4.1 of this review, taking an approach that assumes that the proxy will provide user-specific information runs the risk of not truly capturing the target individuals' needs and preferences (Allsop et al., 2010; Beringer et al., 2013). For instance, the accuracy of the stakeholder's predictions of what may be best for the individual may differ depending on the amount of time stakeholders spend with the individual and whether they engage in similar activities/tasks within a given context (Beringer et al., 2013).

In addition, due to the complexity of the target population, there is a need to change the ways in which traditional methods of input are used and be creative in their application (Brischetto, 2020; Dell'Era & Landoni, 2014). Considering the CCN of the population for whom these systems are designed, it is surprising how few studies within this review took into account the need to obtain input in non-conventional ways. Allen (2005) and Bhattacharya and Basu (2009) were two of the studies which reported the use of sketches and/or models to depict abstract design concepts to the intended users to improve their understanding and conceptualisation of the intended product. The use of talking mats is an example from the literature of an effective method that can facilitate persons with CCN to share their goals, desires and opinions (Bornman & Murphy, 2006). This approach to design has its benefits in that it facilitates persons with CCN's involvement within the design process; however, designers need to ensure that they have a clear picture of what information they intend to receive so as to avoid any possible misinterpretations of the data collected (Nilsson et al., 2015). Further research exploring how to adapt design methods to support the involvement of persons with CCN within the design process is required.

5.6 Product evaluation, outcomes, limitations, and recommendations

As mentioned in Section 2.5 of this review, in order to select the appropriate methods to evaluate the final prototype or end-product, designers must decide on what they want to evaluate (Tao et al., 2020). As the usability of a system can influence the individual's satisfaction of the system and have an impact on whether the individual will continue to use the system (Tosi, 2020), it is unsurprising that most designers evaluated the usability of the designed GS-based AAC system within this review. Other common evaluation constructs that typically fall under usability, such as ease of use, system functioning and user performance (Tao et al., 2020; Tosi, 2020), were also commonly reported within this review.

This review showed that experience prototyping was often used in evaluating the system. Experience prototyping allows the intended user and/or stakeholders to actively engage with the system, which enables the designer to evaluate several system characteristics and to determine aspects such as acceptance and participation when using the (final) prototype (Buchenau & Suri, 2000).

Additionally, many of the same methods used to gather information earlier in the design process were used during the evaluation process, such as questionnaires and observations. The questionnaires used during the evaluation stage of the design were often specific to usability testing and thus SUSs were commonly reported. These SUSs are also mentioned in the literature as commonly used evaluation tools (Al-Arifi et al., 2013; Tao et al., 2020). It can be assumed that questionnaires and/or observations in artificial contexts were often considered as these methods require less time and linguistic demands, and are more cost-effective compared to approaches such as ethnographic observations and focus groups, which pose time, linguistic and financial demands (Dell'Era & Landoni, 2014; Steen, 2011).

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 designs 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 either improve the designed system and/or improve the validity of their studies. Consequently, the findings in this review are consistent with the cyclical relationship between research and development, in that one will inevitably influence the other (Gregor & Hevner, 2013; Wieringa, 2010).

Furthermore, as a by-product of this cyclical relationship, designers will need to continuously develop, analyse and validate GS-based AAC systems in accordance with new research evidence relating to AAC system design and technology (Light et al., 2019; Wieringa, 2010). This is necessary to ensure that the particular AAC system is consistently adapted to fit the changing needs of the user, who will typically require the device for the duration of their lifetime (O'Neill & Wilkinson, 2019; Weed et al., 2011).

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of main findings

Design studies of 28 electronic GS-based AAC systems were explored to provide a broad overview of the design approaches and principles, methods and input considered within design studies, as well as identify the outcomes of the developed products.

It is evident that many GS-based AAC systems were designed as applications to be uploaded onto mobile technology, which is in line with the mobile technology revolution. In addition, it was noted in this review that dynamic, grid-based displays are still popular features among GS-based AAC system designs. An encouraging outcome was the inclusion of customisation features, which ranged from allowing users to capture and add context-specific photographs and vocabulary within their systems to colour-coding GS according to their parts of speech.

Regrettably, there is still inconsistency in how studies report on their design approaches used and the principles followed. Due to the inconsistent terminology in the literature itself regarding design approaches, particularly regarding a UCD and HCD approach, finding a consistent way to report on and discuss design processes can be difficult. It may be beneficial for designers to refer to HCD as a framework which allows for flexibility in its application as there are several HCD approaches one can select that may assist with certain design constraints and/or requirements.

In addition, a general observation from this review highlighted the varying degrees to which each study discussed the population, the task to be accomplished using the AAC system and the context of use. Most studies discussed these components in a general manner, which included broad statements such as designing systems for persons with CCN to improve their everyday communication tasks within multiple day-to-day contexts. This is understandable as the task of ‘communication’ is not limited to specific context, setting or time in a person’s life, it is pervasive, and thus makes a universal solution difficult to accomplish.

Furthermore, including individuals during the initial information gathering stages and the evaluation stages within the design process was evident in many of the design studies within this review. However, as highlighted within this study, the skill of the design team and their knowledge about the person with CCN, the skill of the individuals with CCN as well as time and ethical constraints will influence which user and/or stakeholder will be involved within the process, the role they will play, as well as when they will be involved.

Moreover, information was mainly gathered using methods such as questionnaires, interviews and observations. Similarly, end products/prototypes were evaluated using the abovementioned methods, in addition to experience prototyping. The products were mainly evaluated based on their usability but also included specific factors such as the ease of use, system functioning and user performance. Despite the CCN of the individuals for whom these systems are designed, only two studies discussed using adaptation methods to ensure greater participation of persons with CCN within design studies, therefore highlighting a possible area for further research.

The limited number of available GS-based AAC systems shows that many studies are still ongoing and/or their systems require further adjustments. This exemplifies the cyclical relationship between research and development in that one will influence the other. It also highlights the iterative and complex nature of designing GS-based AAC systems for persons with CCN. Consequently, consolidating the literature regarding the design of such systems is challenging.

6.2 Implications for practice

As this scoping review has only provided a broad overview of the information pertaining to the design studies of GS-based AAC systems, the implications of this review are tentative. With this said, this review has highlighted possible trends and gaps within the literature pertaining to the design studies of GS-based AAC systems. For instance, 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.

Moreover, this review highlighted that many designers seem not to give much prominence to the vocabulary selection considerations but focus more on customisations. While it is good that systems can be customised, this puts programming pressure on the team supporting the person with CCN. Therefore, greater focus could possibly be on pre-programming vocabulary on such systems.

There is a greater need for collaboration between designers and engineers and health professionals. Health 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. In addition to health professionals, there is more work to be done to include individuals with CCN or their communication partners as co-designers. However, it is important to acknowledge power disparity in the roles these persons play.

Furthermore, despite the limited use of non-conventional ways to obtain input or feedback from persons with CCN, it is important to note that various creative methods do exist to facilitate user involvement and for persons with CCN to share their wishes, goals, desires and opinions. Bornman and Murphy (2006) provide a good example of the use of Talking Mats as a strategy.

6.3 Critical evaluation of the study

6.3.1 Strengths

This scoping review is the first attempt to map the literature reporting on the design studies of GS-based AAC systems. The comprehensiveness of the review may provide valuable, introductory information on the documented approaches, principles, input, outcomes, and methods used in the design of such systems to facilitate an understanding of the current state of the field.

The methodological rigour of this review can also be regarded as a strength. This can extend to the rigorous selection process, the high reliability (parentage agreement) and the inclusion and exclusion process in which independent verification by two people was conducted, in addition to the use of a detailed protocol and consultation with the subject librarian and international expert on the search process, as well as on relevant databases to search. Therefore, the transparency of the methods used within this review, as well as accurate reporting, was enhanced.

6.3.2 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).

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. It must also be acknowledged that the inconsistent use of terminology relating to the AAC and/or AT system design approaches made consolidating the literature challenging, and thus one's interpretation of design approaches may vary.

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. It would be possible to analyse the different aspects in more detail with more rigour. For example, the manner in which each of the six HCD principles was applied or not applied in each study could be analysed qualitatively, using thematic analysis. Finer details of the population, such as age, speech and language abilities, their motor functioning, sensory-perceptual skills, and their cognitive functioning, as well as their social, financial, cultural, and linguistic background were also not fully considered. Moreover, the details and consideration of the communication partner within the design studies was not considered, thus relevant information relating to the communication partners may have been omitted.

6.4 Recommendations for further studies

As this study was only a scoping review, the information obtained provides a broad overview of this subject. It is suggested that a systematic review with a focus on the critical appraisal of the quality of GS-based AAC system design studies should be conducted. There is also a need for researchers in the field of AT/AAC design to ensure methodological rigour to establish more reliable, clearly stated and evidence-based results pertaining to the design of GS-based AAC systems.

Moreover, future research can focus on specific trends and gaps highlighted within this review. For example, research on the development of GS-based AAC systems specific to African countries, culture and languages could be explored, particularly since there were no studies found within this review that were based in African countries.

Also, researchers can explore the extent to which the information gathered regarding the HAAT/CAT components influences the decisions made in design studies for GS-based AAC systems. In addition, due to the CCN of the persons for whom the systems are designed, it is particularly important to consider and/or explore (further) how the adaptation of traditional design methods can facilitate the active involvement and accuracy of feedback of persons with CCN within a GS-based AAC system design process.

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Appendix A

Ethics Clearance

Appendix A

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Humanities 100
Since 1919

12 October 2020

Dear Miss JK Bartram

Project Title:	Methods used in the design process of electronic graphic-symbol-based AAC systems: A scoping review
Researcher:	Miss JK Bartram
Supervisor(s):	Prof KM Tönsing Miss RE Morwane
Department:	CAAC
Reference number:	13102894 (HUM003/0920)
Degree:	Masters

Thank you for the application that was submitted for ethical consideration.

The Research Ethics Committee notes that this is a literature-based study and no human subjects are involved.

The application has been **approved** on 12 October 2020 with the assumption that the document(s) are in the public domain. Data collection may therefore commence, along these guidelines.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. However, should the actual research depart significantly from the proposed research, a new research proposal and application for ethical clearance will have to be submitted for approval.

We wish you success with the project.

Sincerely,

Prof Innocent Pikirayi
Deputy Dean: Postgraduate Studies and Research Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail:PGHumanities@up.ac.za

Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Appendix B

Search Protocol

Appendix B

Search Protocol

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

1. *Rationale for the review:*

- Advances in computing and technology have made electronic graphic symbol-based (GS-based) AAC devices a popular option for persons with CCN (McNaughton & Light, 2013; Waller, 2019). Therefore, it would be important to understand the state of the science in GS-based AAC design.
- There is no clear outline for AAC system developers that can inform the design process (Judge et al., 2019). Therefore, mapping information regarding the design process could prove beneficial for future designers.
- All design processes commence with a form of input (Dubberly, 2004). However, there is minimal information on which input sources should be considered and to what extent it is used during the design process (Magnier et al., 2012). Therefore, an overview of the input obtained and used within the design process could prove beneficial for future designers.
- The aim of a design process is to achieve an outcome (in this case, a useful product) (Dubberly, 2004). If there is no evaluation of the usefulness of a product, it remains unclear as to whether the outcome has been achieved. Therefore, it would be important to provide an overview of the evaluation process and the extent to which the product outcomes reflect the needs of the target population.

2. *Review question:*
What design approaches, methods, input obtained, and concomitant product outcomes are documented in the literature regarding the design and development of electronic GS-based AAC systems?

3. *PIO/PEO*
Population: persons with complex communication needs/persons with severe communication disabilities
Issue/exposure/intervention: Design or development
Outcome: Electronic graphic symbol-based augmentative and alternative communication (AAC) device/software

4. *Protocol: Database search*

6.5 Provisional search terms:

'Issue'		***Outcome***
"design process" ***OR*** "development process"	**AND**	"augmentative and alternative communication" ***OR*** AAC ***OR*** "alternative communication"

6.6 *In-/and exclusion criteria*

Inclusion	***Exclusion***
Persons with CCN.	Persons without disability or persons with learning impairments such as dyslexia.
Describes the design and development of an electronic GS-based AAC system.	Describes the design and development of any other AAC systems, such as: • Electronic text-based systems • Non-electronic systems

Appendix B

Inclusion	***Exclusion***
Describes the design and development process.	Describes only customisation, testing, or implementation of a GS-based AAC system.
Describes the input obtained and used within the design process.	Information regarding the input obtained and used within the design process is omitted.
Describe the outcome and evaluation of the product design.	Information on the outcome and evaluation of the product design is omitted.

6.7 *Databases/journals used*

Platforms (with relevant databases)
EBSCOhost (Academic Search Complete, CINAHL, ERIC, Health Source: Nursing/Academic Edition, MEDLINE, ERIC, Humanities, PsycARTICLES, PsycINFO)
ProQuest (Humanities Index, ProQuest Dissertations & Theses Global information, Science Database, Linguistics Collection, Social Science Database)
Scopus
Taylor & Francis (journals)
Wiley Online Library

Individual Databases:
Computer Science Database
IEEE Xplore Digital Library
Advanced Technologies & Aerospace Collection
Linguistics and Language Behaviour Abstracts [LLBA]
Springerlink
Web of Science

6.8 *Limiters*
Language: English
Date: 2000 – 2020

The search results are to be imported into the Covidence software.

Appendix C

Pilot Searches in Computer Science Database

Appendix C

	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Limiters
Concept 1	"complex communication needs" OR CCN	"severe disability" OR "complex communication needs" OR "communication disabilities" OR "special needs"					Language: English Date 2000 – 2020 Scholarly Journals Conference Papers & Proceedings
Concept 2	"augmentative and alternative communication" OR AAC	"augmentative and alternative communication" OR AAC	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	
Concept 3	design OR development	design OR development	design OR development	design OR development OR "design process" OR "development process"	"design process" OR "development process"	"design process" OR "development process"	
Concept 4	"assistive technology" OR device OR application OR software	"assistive technology" OR "electronic device" OR application or software	application OR software				
Concept 5	"graphic symbol" OR picture or image	"graphic symbol"	"graphic symbol"	"graphic symbol"	"graphic symbol"		
Yields	483 067	439 574	486 837	371 398	1 117	1082	

Appendix D

Pilot Searches in EBSCOhost (Academic Search Complete, CINAHL, ERIC, Health Source: Nursing/Academic Edition, MEDLINE, ERIC, Humanities Source, APA PsycARTICLES, and APA PsycINFO)

Appendix D

	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Limiters
Concept 1	"complex communication needs" OR CCN	"complex communication needs" OR CCN		"severe disability" OR "complex communication needs" OR "communication disabilities" OR "special needs"			Language: English Date: 2000 – 2020
Concept 2	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	
Concept 3	design OR development	design OR development OR "design process" OR "development process"	design OR development OR "design process" OR "development process"	design OR development	"design process" OR "development process"	"design process" OR "development process"	
Concept 4	"assistive technology" OR device OR application OR software	"assistive technology" OR device OR application OR software					
Concept 5	"graphic symbol" OR picture OR image	"graphic symbol" OR picture OR image	"graphic symbol"		"graphic symbol"		
Yields	392	9433	289	108	6	440	

Appendix E

Pilot Searches in ProQuest (Humanities Index, ProQuest Dissertations & Theses Global information, Science Database, Linguistics Collection, and Social Science Database)

Appendix E

	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Limiters
Concept 1	"complex communication needs" OR CCN				"severe disability" OR "complex communication needs" OR "communication disabilities" OR "special needs"		Language: English Date: 2000 – 2020
Concept 2	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	
Concept 3	design OR development	design OR development	design OR development OR "design process" OR "development process"	"design process" OR "development process"	"design process" OR "development process"	"design process" OR "development process"	
Concept 4	"assistive technology" OR device OR software						
Concept 5	"graphic symbol"	"graphic symbol"	"graphic symbol"	"graphic symbol" OR symbol			
Yields	27 490 616	131 505	11 601 557	435	780	484	

Appendix F

Pilot Searches in IEE Xplore Digital Library

Appendix F

	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Limiters
Concept 1	"complex communication needs" OR CCN		"severe disability" OR "complex communication needs" OR "communication disabilities" OR "special needs"				Language: English Date: 2000 – 2020 Journals & Conferences
Concept 2	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	"augmentative and alternative communication" OR AAC OR "alternative communication"	
Concept 3	"design process" OR "development process"	"design process" OR "development process"	"design process" OR "development process"	"design process" OR "development process"	design OR development	"design process" OR "development process"	
Concept 4							
Concept 5				"graphic symbol" OR symbol			
Yields	0	0	70	2	6060	2172	

Appendix G

Pilot Searches in Scopus

Appendix G

	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Limiters
Concept 1	“complex communication needs” OR CCN	“severe disability” OR “complex communication needs” OR “communication disabilities” OR “special needs”					Language: English Date: 2000 – 2020
Concept 2	“augmentative and alternative communication” OR AAC OR “alternative communication”	“augmentative and alternative communication” OR AAC OR “alternative communication”	“augmentative and alternative communication” OR AAC OR “alternative communication”	“augmentative and alternative communication” OR AAC OR “alternative communication”	“augmentative and alternative communication” OR AAC OR “alternative communication”	“augmentative and alternative communication” OR AAC OR “alternative communication”	
Concept 3	design OR development	"design process" OR "devel opment process"	"design process" OR "devel opment process"	"design process" OR "development process"	"design process" OR "devel opment process"	"design process" OR "devel opment process"	
Concept 4	“assistive technology” OR device OR software						
Concept 5	“graphic symbol”		“graphic symbol”	symbol OR picture	“graphic symbol” OR symbol		
Yields	638	66	72	54	34	588	

Appendix H

A comparison of search results between three search strings

Appendix H

	("augmentative and alternative communication" OR AAC OR "alternative communication") AND ("design process" OR "development process")		("severe disability" OR "complex communication needs" OR "communication disabilities" OR "special needs") AND ("augmentative and alternative communication" OR AAC OR "alternative communication") AND ("design process" OR "development process")		("augmentative and alternative communication" OR AAC OR "alternative communication") AND ("design process" OR "development process") AND ("graphic symbol")	
	Yields	Hits	Yields	Hits	Yields	Hits
Scopus	590	✓	66	✓	34	✓
EBSCOhost	191	✓	108	✓	6	X
ProQuest	674	✓	290	X	435	✓
IEE Xplore Digital Library	2265	✓	70	✓	2	X
Taylor & Francis	209	✓	37	X	72	✓
Wiley Online Journals	309	✓	47	X	96	✓
Computer Science database	1124	✓	178	✓	1112	✓
LLBA	1920	X	429	X	1917	X
Advanced Technology	334	✓	192	X	313	✓
SpringerLink	557	✓	636	✓	141	✓
Science Direct	829	X	71	X	55	X
Emerald Insight	148	X	84	X	65	X
Web of Science	27	✓	2	X	5	X

[a] Hits are records that meet the inclusion criteria. A tick (✓) indicates that hits were included in the results. A cross (X) indicates that results omit important hits or contain too many irrelevant citations.

Appendix I

Title and Abstract Screening Tool

Appendix I

Abstract and Title Screening Tool

Title of Article	
Authors	
Year	

1. Does the citation describe the systems designed on a graphic symbol-based AAC system?
   - ☐ Yes
   - ☐ No
   - ☐ Unclear
2. Does the citation describe the design and development process?
   - ☐ Yes
   - ☐ No
   - ☐ Unclear
3. Does the citation describe the input obtained and used within the design process?
   - ☐ Yes
   - ☐ No
   - ☐ Unclear
4. Does the citation describe the evaluation and/or outcome of the product design?
   - ☐ Yes
   - ☐ No
   - ☐ Unclear

<u>Reviewer decision:</u>

- If the reviewer answered NO to any of the questions, the citation will be excluded.
- If the reviewer answered YES to all the questions, the citation will be included for full-text screening.
- If the reviewer answered UNCLEAR to any or all the questions, the citation will be included within the full-text screening.

Appendix J

Data extraction form

Appendix J

Criteria	Category	Definitions (where applicable)	Reporting Objectives
General description			
Date of form completion		N/A	None
Name of person extracting data		N/A	None
Author/s		N/A	None
Year of publication		N/A	To obtain the most current and relevant publications.
Title		N/A	None
Aim of the research study		N/A	To obtain qualitative analysis of the research aims and thus further facilitate the link between the aims and the main finding of the study. This including identifying research limitations (gaps) and future recommendations.
Description of the AAC system designed			
Description of intended product	Name of product designed	N/A	
	Dedicated AAC device	Dedicated devices are aided AAC systems that are specifically designed to support communication for persons with CCN and thus cannot be used for other functions such as sending emails or making phone calls (McNaughton & Light, 2013).	
	Non-dedicated AAC device i.e., AAC app on android system	A non-dedicated AAC device encompasses an AAC software or application on any mainstream hardware device, such as a tablet or iPad (McNaughton & Light, 2013; York & Fabrikant, 2011).	
Characteristics of the electronic GS-based AAC system (Gosnell et al., 2011).	**Physical** Only select these items if the article explicitly states these/other physical aspects.		To describe the features of the system designed.
	Portability	N/A	
	Light sensitivity	N/A	
	Other	N/A	
	Display		
	Static	GS are displayed on one page (Judge et al., 2019).	

Appendix J

Criteria	Category	Definitions (where applicable)	Reporting Objectives
	Dynamic	Individuals can navigate through multiple pages to locate various GS (Judge et al., 2019).	
	Grid display	GS are displayed in a grid-format (Light, et al., 2019).	
	Visual Scene display (VSD)	A VSD uses pictures or photographs that depict a situation, place, or experience that is familiar to the learner (Light, et al., 2019).	
	Number of cells	N/A	
	Colour coding	N/A	
	Size of symbols	N/A	
	Text (e.g., font, size)	N/A	
	Other	N/A	
	Voice output settings Only select these items if the article explicitly states the type of voice output feature used.		
	Synthesised speech output	Computer generated speech output (Light & Drager, 2002).	
	Digitised speech output	Recorded human voice (Light & Drager, 2002).	
	Amplification (e.g., volume, pitch, rate)	N/A	
	Other	N/A	
	Language features Only select these items if the article explicitly states the type of language feature used.		
	Graphic symbols		
	AAC symbol libraries	AAC symbol libraries are commercially available GS sets and include, Imagine Symbols, Picture Communication Symbols (PCS), and Widgit Symbols to name a few (Beukelman & Light, 2020).	
	Photographs	N/A	
	Icons/symbols (e.g., function buttons such as back, home, speak)	N/A	
	Other images (e.g., clipart)	N/A	
	Other	N/A	
	Vocabulary		
	Polysemy (multiple semantic meaning)	Also known as semantic compaction (Phuphatana et al., 2018).	
	Customisation	N/A	
	Core words	N/A	
	Fringe words	N/A	

Appendix J

Criteria	Category	Definitions (where applicable)	Reporting Objectives
	Word or sentence prediction	N/A	
	Access to morphology (e.g., change tenses) or syntax (grammatically correct sentences)	N/A	
	Other	N/A	
	Access		
	Touch screen	N/A	
	Eye Gaze	N/A	
	Switches	N/A	
	Pointer	N/A	
	Other	N/A	
Population ***write down the information authors provide regarding the population for whom the product was designed.**			
Description of the population for whom the product is designed.	☐ Age ☐ Diagnosis ☐ Language/cultural background	N/A	
Design methods (approaches) and components ***only select these items if the article explicitly states which design approach they have used.**			
Human Centred Design (HCD) approach and/or other approach underlying the design process (Sanders & Stappers, 2008).	☐ Participatory design ☐ Empathic design ☐ Contextual design ☐ Ethnography design ☐ Co-design approach ☐ Lead user approach ☐ User-centred design (UCD) ☐ Other	N/A	To determine the frequency and/or use of design approach (with focus on HCD).
Six HCD principles as set out in the ISO 9241-210: 2019 standard as cited in Shekhovtsova et al. (2020).	Design displays an awareness of the users, their tasks and environment	N/A	To determine the extent to which the six HCD principles are used and reported.
	The users are involved in the design process	N/A	
	The feedback provided by users is displayed within the design	N/A	
	The process is iterative	N/A	
	The users' experience is addressed holistically within the design.	N/A	
	Multidisciplinary skills and perspectives have been incorporated within the design	N/A	

Appendix J

Criteria	Category	Definitions (where applicable)	Reporting Objectives
Input obtained ***the information obtained here can include any information that the researcher has provided about the target population (which can include their stakeholders)**			
Content of the input obtained based on the components of the HAAT model (Cook et al., 2019).	☐ Human (population) ☐ Task (participation) ☐ Context (environment)	N/A	To describe the input that is obtained by designers to better understand the user (human), the task, and the contexts in which the system may be used.
Method in which input was obtained specific to the initial information gathering stages of the design process, which may include prototyping (Tao et al., 2020). ***This section will exclude final prototype evaluations.**	☐ Focus groups ☐ Observations ☐ Interviews ☐ Questionnaire/Survey ☐ Consulting the literature **(information gathered must pertain to gaining information on the system/user requirements)** ☐ Other	N/A	To determine how information is sourced.
Persons involved within the design process			
Author/s disciplinary or institutional affiliation	N/A	N/A	
Persons involved, in addition to the authors (Ogletree et al., 2018; Sanders & Stappers, 2008). ***Information gathered here should include all parties involved within the design process.**	☐ Designer/manufacturer (additional to the authors) ☐ Users (certain population of users) ☐ Parent/caregiver ☐ Educator ☐ Health professionals (speech therapist, occupational therapist, physiotherapist) ☐ Linguist ☐ Computer scientist ☐ Other	N/A	To determine to what extent a multidisciplinary approach is used.
User and/or Stakeholder involvement (Damodaran, 1996; Galway et al., 2013; Magnier et al., 2012). ***This section is specific to the users and/or stakeholders.**	**Role**		To determine to what extent the individual and their stakeholders are included within the design process. Specifically looking at their role, what step/s of the
	Informative	Users/stakeholders play a passive role in the design process whereby they are used to gain more information regarding their needs, their task, and their context as well as provide more information on the usefulness of a product (Dell'Era & Landoni, 2014). Techniques often used to gain such information are	

Appendix J

Criteria	Category	Definitions (where applicable)	Reporting Objectives
		observations, focus groups, interviews and questionnaires (Dell'Era & Landoni, 2014).	process they are included in, and how they are included.
	Participatory	Users/stakeholders play an active role in the design, development and innovation of a product (Dell'Era & Landoni, 2014). Stakeholders are seen as co-creators and work with the designer in a collaborative manner (Dell'Era & Landoni, 2014).	
	Other	N/A	
	In which step(s) of the design are they included?		
	Information gathering (Stages 1-2)	N/A	
	Only with prototype (Stage 3)	N/A	
	Product testing (Stage 4)	N/A	
	Other	N/A	
	How do designers receive information from users or stakeholders?		
	Focus groups	N/A	
	Observations	N/A	
	Interviews	N/A	
	Questionnaire/Survey	N/A	
	Experiment with prototype	Experience prototyping is the active engagement with prototypes that aim to convey an experience with a system/product (Buchenau & Suri, 2000)	
	Other	N/A	
	Reason for limited/no input from stakeholders (if applicable)		
	Ethical requirements to observe group	N/A	
	Cost constraints	N/A	
	Time constraints	N/A	
	Other	N/A	
Product evaluation and outcomes			
Methods used in the evaluation process (Dell'Era & Landoni, 2014; Wakkary, 2007). ***This section will include final prototypes (if they were evaluated).**	☐ Experience prototyping ☐ Applied ethnography ☐ Simulation tools ☐ Scenarios ☐ Participatory workshops ☐ Questionnaires ☐ Focus groups ☐ Other	Applied ethnography is a practice in which the researcher dedicates substantial time to observe the target population in a natural context of use i.e., how the individual uses the product within their environment (Dell'Era & Landoni, 2014).	To describe the evaluation of the product design including how the product is evaluated, what constructs are evaluated, and the extent to which the product meets the needs of the target population.

Appendix J

Criteria	Category	Definitions (where applicable)	Reporting Objectives
Constructs evaluated (Tao et al., 2020; Tosi, 2020) ***The constructs added here are possible examples and thus if a study does not mention any of these factors, please indicate what they did evaluate in the 'other' column.**	Participation (user)	This refers to testing the users' (or proxy's) ability to/extent to which they can participate in a specific task using the designed product (Tosi, 2020).	
	Performance	This refers to how well the designed product operates/functions/works and therefore, it is testing the functional performance of the system (Tao et al., 2020).	
	Usability	Usability is defined in the ISO 9241-210 standard, as seen in Tosi (2020), as an overarching construct that encompasses the extent to which a system or product meets the needs of the individual and can be used to achieve their specific goals with effectiveness, efficiency, and satisfaction.	
	Ease of use	This refers to users ability to carry out and successfully complete a specific task (Tosi, 2020).	
	Quality of life	N/A	
	Acceptance	N/A	
	Other	N/A	
Outcomes of evaluation.	☐ Meets requirements ☐ Partially meets requirements ☐ Did not meet requirements ☐ Requires redesign/adjustments	N/A	
Availability of the product.	☐ Commercially available for purchase ☐ Freely available online ☐ Prototype available ☐ Product not available ☐ Not reported	N/A	
Limitations and recommendations			
Constraints experienced in the design process as reported by authors (Dell'Era & Landoni, 2014; Light et al., 2019).	☐ Financial ☐ Time ☐ Technology ☐ Team expertise ☐ Other	N/A	To determine the extent to which designers experienced limitations that may have influenced decision-making/ design processes.
Recommendations.	☐ Further research ☐ Further development ☐ Clinical use ☐ User feedback ☐ None reported	N/A	To identify the current state of and gaps in the literature on electronic GS-based product design.

Appendix K

Summary of the reported main characteristics of electronic GS-based AAC systems

Appendix K

Author	Display	Graphic symbols	Vocabulary features	Voice output	Access
Al-Arifi et al. (2013)	Dynamic, grid display	PCS	PECS approach:' I want' and customisable request items, quick replies, favourite list.	Digitised and synthesised voice output	Touch screen.
Allen (2005)	Not reported	Not reported	Not reported	Synthesised voice output. Digital volume control was also included.	Keyboard
An et al. (2017)	Dynamic, grid display. Layout settings allows the number of GS displayed on the screen to change from one to nine (p.7).	Built-in picture library (not further specified) and digital photographs.	The vocabulary can be personalised (i.e., customised).	Digitised and synthesised voice output	Touch screen
Babic et al. (2015)	Display is included older AAC components, but which components were not specified.	ARASAAC, Mulberry and Sclera were included. The text accompanying the GS and the symbol size can be adjusted.	The type of words included were not specified, however, the individual can personalise the application and vocabulary.	Makes use of sound recordings (p. 5), therefore digitised voice output	Touch screen
Bhattacharya and Basu (2009)	Dynamic grid display presenting with 18 icons in three rows (i.e., a maximum of 36 icons displayed on a screen at a time).	Some GS were taken from a stamp book prepared by the Indian Institute of Cerebral Palsy. The size of the GS can be adjusted.	Vocabulary included verbs, nouns, adjectives, and adverbs. Sentences can be generated in past, present and future tense.	Text-to-speech system, therefore synthesised voice output with focus on the "Indian language" (p. 174).	Scanning and access switch-based input
Boyd-Graber et al. (2006)	Dynamic display representing storyboards but also includes single, larger icons for appointments (p. 156).	GS were taken from the Lingraphica symbol library. Digital photographs were also included. The size of the text accompanying the GS/photograph could be adjusted.	The type of words included were not specified, however, the individual could personalise the pictures, voice output and text included on their system (i.e., vocabulary).	Digitised voice output	Touch screen with the option for a keyboard, conventional mouse and track-ball (p. 152).
Cheung et al. (2014)	Dynamic interface presenting with a 4 x 6 grid display.	Prestored photographs or photographs taken by the user and/or stakeholder was included. In addition, to ensure easier identification "each word/phrase category has different coloured background and border…"	The system is a customisable display and thus the user can manage and add words or phrases to the system and the corresponding picture/text. The system allows for the vocabulary to	Digitised and synthesised voice output	Touch screen and scanning control

Appendix K

Author	Display	Graphic symbols	Vocabulary features	Voice output	Access
		(p. 192). The font size of the accompanying text can be changed.	be separated into categories such as nouns, verbs, adjectives, time and quantifiers.		
da Silva et al. (2018)	Dynamic grid display that can be adapted to present either one or four pictures at a time.	"168 pictographic symbols were included, of which 40 were created in the Corel Draw X7 image edition tool, and 128 were extracted from the ARASAAC portal" (p. 169). Digital photographs were also included as well as various function icons and text that accompanied the GS. Pictures can be enlarged.	Not reported	Synthesised voice output	Touch screen and switches
de Faria Borges et al. (2014)	Dynamic, grid display	GS in the form of photographs was included as well as custom designed drawings.	The system is designed to grow with the user and thus vocabulary in terms of verb tenses and modifications, nouns, clause coordination and subordination and so on, can be added gradually.	Sentences are to be voiced	Touch screen
Daemen et al. (2007)	Dynamic, VSD to represent a storytelling application	Photographs were included as GS which can be customised. Function icons were also included.	Not reported	Digitised voice output	Touch screen
de Oliveira et al. (2016)	Dynamic, grid display	GS were taken from the "works of Sergio Palao to CATEDU and published under the Creative Commons license" (p. 133). The GS were colour coded using the Fitzgerald key. The system also included function icons and text to accompany the GS.	The vocabulary selected for the system was not described. However, the system does allow for customisation.	Digitised and synthesised voice output	Touch screen and mouse was reported as a trigger for scanning and pressing buttons
Di Mascio et al. (2019)	Dynamic interface that allows for three to six cells represented in a grid display. The display layout can also be personalised.	A GS AAC library as well as photographs were included. Text that accompanied the GS was also included.	The vocabulary selected for the system was not described. However, the system's content to be personalised.	Digitised and synthesised voice output	Touch screen
Hayes et al. (2010)	Dynamic interface that allows for a flexible grid display layout.	A GS library was reported and included "standard iconography" (p.	The vocabulary selected for the system was not described. However, the	Digitised and synthesised voice output	Touch screen

Author	Display	Graphic symbols	Vocabulary features	Voice output	Access
		668). Digital photographs were reported.	system does allow for customisation.		
Hervás et al. (2020)	Dynamic, grid display representing a maximum of 12 GS per page.	GS were taken from the ARASAAC library. The function icons of the system were also included. The GS were colour-coded based on their corresponding part- of-speech tags.	The system allowed access to parts of speech. It also allowed for picture (word) prediction. The system was also customisable.	Synthesised voice output	Touch screen
Hill (2006)	Not reported	GS were icons from other European AAC systems. Semantic compaction (i.e., multiple semantic meanings per GS) was reported. The size of GS can be adapted.	A list of core words (vocabulary) was included within the system.	Text-to-speech system, therefore synthesised voice output	Not reported
Hine et al. (2003)	Multimedia VSD that can display multiple GS on a page (e.g., 5 smaller GS per category and one enlarged GS).	Photographs with text to accompany it were included and can be customised.	Not reported	Not reported but it was recommended for future developments.	Touch screen as it was found to be easier than using a pointer, mouse or keypad.
Hirotomi (2018)	Dynamic, grid display representing five columns with 12 GS per columns. The display was designed to flow from right to left according to the Arabic language.	Pictorial symbols, freehand drawings and photographs were included, These GS can colour-coded and customised.	Core and fringe vocabulary was included. In addition, a web-image search could be conducted for 'just-in-time' vocabulary.	Synthesised voice output	Touch screen
Jafi et al. (2020)	Dynamic, grid display with no than 12 GS per page. The display changes based on the user's location.	The type of GS were not specified (i.e., they were called symbols) but function icons were included.	Vocabulary included pronouns, verbs, and commonly used words/terms.	Synthesised voice output	Eye gaze using a webcam was reported. Mouse-based access was also offered.
Karita (2017)	Dynamic, grid display that represents one to nine button screens to represent each message.	GS were included from other AAC systems. The GS can be resized. Text was also included	Vocabulary interface changes based on location	Digitised voice output	Touch screen
Lubas et al. (2014)	Dynamic, grid display	Photographs and clipart were reported as GS. These can be customised, colour-coded and enlarged. Text also included. The GS are categorised within the display based on time they were taken.	Not reported	Digitised voice output	Touch screen

Appendix K

Author	Display	Graphic symbols	Vocabulary features	Voice output	Access
Mahmud et al. (2013)	Dynamic, VSD which presents six contextual photographs in a cluster.	Photographs were included and can be enlarged. Text accompanying the photograph was also included and function icons.	Not reported	Does not specify	Does not specify the type of access but does report on the user being able to select, drag and edit pictures (p. 310).
Martin et al. (2019)	Dynamic, VSD	GS were taken from the ARASAAC library and function icons were discussed.	Not reported	Digitised voice output	Touch screen.
Mendes and Correia (2013)	Dynamic, grid display	Widgit literacy symbols, photographs and the corresponding text was included.	Not reported	Digitised voice output	Touch screen.
Rodríguez-Sedano et al. (2017)	Dynamic, grid display	PCS and photographs were reported as GS. Text font size was also included.	Not reported	Does not specify the type of voice output	Does not specify.
Saturno et al. (2015)	Dynamic, grid display	PCS and photographs were reported as GS. Text was also included.	Sentence prediction and storing phrases was included. Vocabulary can be adapted based on school subjects.	Synthesised voice output	A joystick was included for direct selection of GS. A stapler device and scanning was also reported.
Stančić et al. (2013)	Not reported	GS included the users' "own private symbol galleries with symbols having specific meaning for them" (p. 702). This included photos or specifically created images. Text and colour-coding were also included.	Not reported	Digitised and synthesised voice output. Sounds can also be downloaded from the 'the web' (p. 702).	Touch screen, keyboard and mouse were reported
van de Sandt-Koenderman et al. (2005)	Dynamic, grid display	Photographs, pictures, symbols, sketching, and typing were included and are customisable.	Not reported	Digitised and synthesised voice output	Touch screen and keyboard.
Williams et al. (2015)	Dynamic display	Symbol-based dictionaries and photographs were included and are customisable. Text and GS colour-coding was also included.	The vocabulary selected for the system was not described. However, the use of vocabulary prompts was discussed.	Text-to-speech system, therefore synthesised voice output.	Touch screen and a touch pad on the left-hand-side of the system was included

Appendix L

Turnitin Report

Appendix L

Document Viewer

Turnitin Originality Report

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Mini-dissertation final By JK (Jessica) Bartram

Similarity Index	Similarity by Source	
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Appendix M

Statement from Language Editor

Appendix M

Toni Muir
Writer and Editor

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24 June 2021

To Whom It May Concern,

I hereby confirm that I conducted the language editing of the mini-dissertation, 'Designing electronic graphic symbol-based AAC systems: A scoping review', by Jessica Kim Bartram.

Kind regards,

Toni Ingrid Muir
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