Intelligent assistive technology devices for persons with dementia: A scoping review

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Abstract

Assistive technology (AT) with context-aware computing and artificial intelligence capabilities can be applied to address cognitive and communication impairments experienced by persons with dementia (PwD). This paper aims to provide an overview of current literature regarding some characteristics of intelligent assistive technology devices (IATDs) for cognitive and communicative impairments of PwD. It also aims to identify the areas of impairment addressed by these IATDs.

A multi-faceted systematic search strategy yielded records. Predefined criteria were applied for inclusion and data extraction. Thereafter data was thematically analysed and synthesised. This review demonstrates that almost all of the research involving IATDs has focused on cognitive impairments of PwD and has not yet evolved past the conceptual or prototype stages of development. Summaries of commercially available IATDs for PwD and relevant prototypes are provided at the end of this review.

This research concluded that IATDs for PwD targeting cognition and communication problems primarily focus on social robots, and that they address cognitive impairments of attention, affect, and social-pragmatic communicative impairments. Future research endeavours concerning AT for PwD should explore collaboration between computer engineering and health practitioners to address the identified gaps. This may contribute to the available information for evidence-based decision making for PwD.

Keywords: augmentative and alternative communication, assistive devices, assistive technology, communication, dementia, intelligent technology

Introduction

Assistive technology is an umbrella term for devices or product systems that could be customised or modified to enable, improve, simplify or maintain the functional capabilities and independence of persons with disabilities, thus advancing their well-being and participation in various areas of their lives (Gibson et al., 2016; van Niekerk, Dada, Tönsing, & Boshoff, 2018; WHO, 2018).

The main goal of assistive technology (AT) for persons with dementia (PwD) is to enable them to maximise their mental, physical and social functions to continue leading independent and purposeful lives and to continue participating in social networks (Mokhtari et al., 2012). The integration of technology into care for PwD is a significant opportunity, as it can potentially reshape dementia care (Hung et al., 2019). Innovations in the technological field can slow the onset of symptoms by keeping PwD cognitively active in the domains of complex attention, executive function, language, learning and memory, perceptual-motor or social cognition and lengthening their independent living (APA, 2013; Evans, Brown, Coughlan, Lawson, & Craven, 2011; Klimova, Valis, & Kuca, 2018).

Communication difficulties are a common symptom of dementia (Hickey & Bourgeois, 2018). The communication challenges associated with dementia reflect underlying impairments in memory, attention and executive functioning (Mahendra, Hickey, & Bourgeois, 2018). PwD often experience difficulty with auditory comprehension of abstract language. Although PwD often retain sound and speech production, expressive language difficulties are noted in word-meaning and word retrieval (Banovic, Junuzovic-Zunic, & Sinanovic, 2018). Progressively, the ability to initiate or maintain conversational topics regresses and PwD may withdraw from social interaction which increases isolation and loneliness (Hickey & Bourgeois, 2018).

Augmentative and alternative communication (AAC) is beneficial to support the degenerative cognitive-communication difficulties experienced by PwD (Fried-Oken, Mooney & Peters, 2015). As a scientific field of clinical practice, AAC applies evidence-based techniques and strategies that offer communication support through unaided or aided systems (American Speech-Language-Hearing Association [ASHA], n.d). Unaided systems do not require any tools, devices or technology but the use of one's body (e.g. manual signs, facial expressions) (ASHA, 2019). Aided systems are tools or devices, which are further categorised as either non-electronic, paper-based solutions (e.g. picture communication books) or electronic, technologically dependent devices (e.g. computer technology) (ASHA, n.d.; Waller, 2019). AAC may also include assistive devices to augment natural communication abilities and to support communication and companionship, promote relationships and thereby reduce social isolation of PwD (Evans et al., 2011; Goodall, Taraldsen, & Serrano, 2020).

AAC interventions for PwD compensate for, maintain, or enhance memory, communication functions and participation in life activities for PwD. For instance, AAC interventions focus on the strengths of the PwD (e.g. reading skills) to support memory (e.g. pictures with written labels as visual aids/reminders) (Lanzi, Burshnic, & Bourgeois, 2017). The majority of AAC interventions for PwD still involve the use of non-electronic systems. However, there is a shift to exploring technology with natural language processing (computer algorithms that can analyse, adapt, supplement, or generate human language) in AAC devices for PwD (Higginbotham, Lesher, Moulton, & Roark, 2012; May, Dada, & Murray, 2019). PwD are being involved in the collaborative development of conversational topics on non-electronic aids, as well as in the development of electronic aids to promote independence and personal agency, as advised by the person-centred care approach. The evidence in this regard is still emerging (May et al., 2019).

New AAC technologies, for example artificial intelligence, may benefit individuals with degenerative conditions who use AAC (Light, McNaughton, Beukelman, Fager, Fried-Oken, Jakobs & Jakobs, 2019). Trends in assistive devices have moved toward context-aware computing and the use of artificial intelligence. Systems that are context-aware can sense information about a person and remember the information to reduce cognitive effort and facilitate computer-user communication (Mihailidis & Fernie, 2002). Technologies that amplify or augment human abilities have proliferated as service robots and home automation equipment with artificial intelligence and are becoming more commonplace in users' lives (McMurray et al., 2017). Sennott, Akagi, Lee and Rhodes (2019) defined artificial intelligence as a machine's capability to mimic human intelligence with the goal to develop machines that are able to use human intelligence characteristics. These traits include emotion, creativity, language, self-awareness, learning, logic, planning, and reasoning to solve problems and to adapt to changing environments. The ultimate goal of AAC devices and systems with artificial intelligence capabilities is to provide enhanced methods to solve the challenges of participation when the communication needs of persons with complex communication needs are hampered by their speech or language abilities (Sennott et al., 2019).

Artificial intelligence (AI), a relatively new field in science and engineering, has brought about intelligent assistive technology devices (IATDs). IATDs have the ability to support or increase human abilities or activities, while sensing and responding to the user's needs and adapting to the changing environment (McMurray et al., 2017; Russel

& Norvig, 2014). IATDs employ algorithms for mobile and ambient activity recognition, context modelling, anomaly detection, location and identity distinguishing, and automatic planning and scheduling (Rashidi & Mihailidis, 2013).

Recently, there has been emerging interest in IATDs for PwD. This has been noted in a synopsis of research by Ienca et al. (2017), which indicated that distributed systems such as smart home systems dominated the largest portion of indexed technologies for PwD, followed by assistive robots and mobility aids (Liddle, 2017). Furthermore, researchers inspected augmented reality applications for people with cognitive impairments and found that these provide customised directions, cues and supplemental information to PwD (Zanwar, Heyn, McGrew, & Raji, 2018). Context-aware and augmented reality technology have also been applied to support people with cognitive impairments, including PwD, with performance of tasks that require multiple steps (Lancioni et al., 2021).

Klimova, Maresova and Kuca (2016) examined assistive technologies that are broadly applied to the language disorders of PwD and concluded that especially AAC technologies can significantly improve and substitute the spoken and written communication of PwD. May et al. (2019) specifically reviewed current AAC interventions for PwD and noted that electronic aids for memory and communication impairments include technology such as wearable computing devices, just-in-time programming and natural language processing. Similarly, a systematic mapping study indicated that academic research on software-based assistive devices focused on providing assistance to cope with socialisation, leisure and cognitive difficulties (Asghar, Cang, & Yu, 2016). However, the study highlighted that commercially available software-based assistive devices for health and activity monitoring and cognitive difficulties receive more attention (Asghar et al., 2016).

More recently, the application of IATDs expanded to communication and socio-contextual use (McMurray et al., 2017). Bemelmans, Gelderblom, Jonker and De Witte (2012) reviewed studies on socially assistive robotic systems used for the care of elderly persons, of which many were PwD.

While the use of IATDs has shown positive psycho-social and physiological outcomes, their adoption rate by PwD remains lower than expected (Bemelmans et al., 2012). Possible reasons for this may be the inadequate information transfer and dissemination between technology development and medical implementation, the lack of clinical validation of IATDs, and clinicians being unaware of new IATDs and their applicability in dementia care (Ienca et al., 2017). Although previous reviews such as by Bharucha et al. (2009) encompassed many technologies, only a few IATDs have been investigated with PwD (Gagnon-Roy et al., 2017).

A review of currently available IATDs to support communication and cognition in PwD has the potential to increase knowledge on the availability of technologies for PwD. This information may possibly contribute towards an improvement in the adoption rates of IATDs for PwD. The clinical significance of IATD uptake provides the rationale for the current review. By considering a wide scope of record types, this review aims to identify the cognitive and communicative domains addressed by IATDs, the availability of these IATDs to the general public, and the diagnostic subgroups of PwD who have been exposed to the IATDs in research. This is an attempt to synthesise information from the technology development and medical fields for the benefit of PwD.

Methodology

The aim of this paper is to synthesise the current research evidence of available IATDs to address the impaired cognitive and communicative functions of PwD by identifying the following as sub-aims:

(1) The diagnostic subgroup and severity of dementia of the populations exposed to IATDs
(2) The cognitive and communicative domains targeted by the IATDs
(3) The availability for purchase of the IATDs to the public for the care of PwD

A scoping study and analytical reinterpretation of the literature is able to map the key concepts, main sources and types of evidence available in the relatively new field of IATDs (Arksey & O'Malley, 2005; Levac, Colquhoun, & O'Brien, 2010). Qualitative data analysis was applied through the process of inductive analysis, where specific data was synthesised into general categories and patterns (McMillan & Schumacher, 2014). These procedures summarised research findings and identified research gaps in the existing literature to guide further research (Arksey & O'Malley, 2005). The PRISMA-ScS (Preferred Reporting Items for Systematic reviews and Meta-Analysis extension for Scoping Reviews) checklist (Tricco et al., 2018) was followed to increase methodological transparency.

Pilot searches tested technical adequacy, feasibility of the search terms and applicability of the inclusion and exclusion criteria, and determined whether any changes to the protocol were required (Brereton, Kitchenham, Budgen, Turner, & Khalil, 2007).

Information sources

Data was compiled from a multi-faceted search strategy to avoid a biased yield (Schlosser, Wendt, Angermeier, & Shetty, 2005). A combination of search methods was utilised. These included electronic database platform searches (i.e., EBSCOhost and ProQuest), single electronic database searches (i.e., IEEE Xplore DL and ACM Digital Library) and hand searches of electronic journals identified through literature readings for the period 2010 to 2020. These search methods are specified as follows:

Firstly, electronic database platform searches included: Scopus platform, EBSCOhost platform (including databases Academic Search Complete, The Cumulative Index to Nursing and Allied Health Literature [CINAHL], E-Journals, Education Resources Information Center [ERIC], Family & Society Studies Worldwide, Health Source: Nursing/Academic Edition, MEDLINE, PsycARTICLES, and PsycINFO), ProQuest platform (including databases Humanities Index, ProQuest Dissertations & Theses Global, Science Database, Advanced Technologies & Aerospace Collection, ERIC, Linguistics and Language Behavior Abstracts [LLBA], Linguistics Database and Social Science Database).

Secondly, electronic database searches included IEEE Xplore DL database and ACM Digital Library database. The electronic database platform and single electronic database searches contained search terms and publication requirements, namely published in English in the period 2010–2020. To ensure that any articles added to the platforms or databases after the systematic search date are also sourced, the RSS (Really Simple Syndication) feeds of the searches were applied. This feature allowed updates concerning the search yields from the library databases. Where RSS feeds were not possible, searches were repeated, and duplicates were removed to identify new additions.

Thirdly, hand searches of electronic journals identified through literature readings for the period of 2010–2020 were also included in the systematic search, namely Alzheimer's & Dementia: The Journal of the Alzheimer's Association, Assistive Technology, and Augmentative and Alternative Communication. Figure 1 illustrates the yields from above search strategies.

Eligibility criteria

To collate a set of records that would provide accurate answers to the research question, a set of inclusion and exclusion criteria was based on the framework recommended for qualitative research reviews, i.e. Population, Exposure and Outcome (PEO) (Butler, Hall, & Copnell, 2016). By applying the inclusion and exclusion criteria, irrelevant records were excluded, and only primary research of PwD who were exposed to IATDs and which reported cognitive and communicative outcomes of the PwD, were included. Two reviewers independently performed a screening protocol for each record by reading the title and abstract. Each reviewed the total number of records using Covidence software (Veritas Health Innovation, n.d.). To conduct the screening conservatively, any records with disagreements between the reviewers were escalated to full-text screening. Eligibility criteria included the following:

- POPULATION: Adults (18 years +) with degenerative mild to severe primary dementia, with insidious onset, as well as gradual progression of impairment affecting one or more cognitive domains (APA, 2013), including dementia due to Alzheimer's disease, frontotemporal dementia (e.g. primary progressive aphasia), dementia with Lewy bodies.

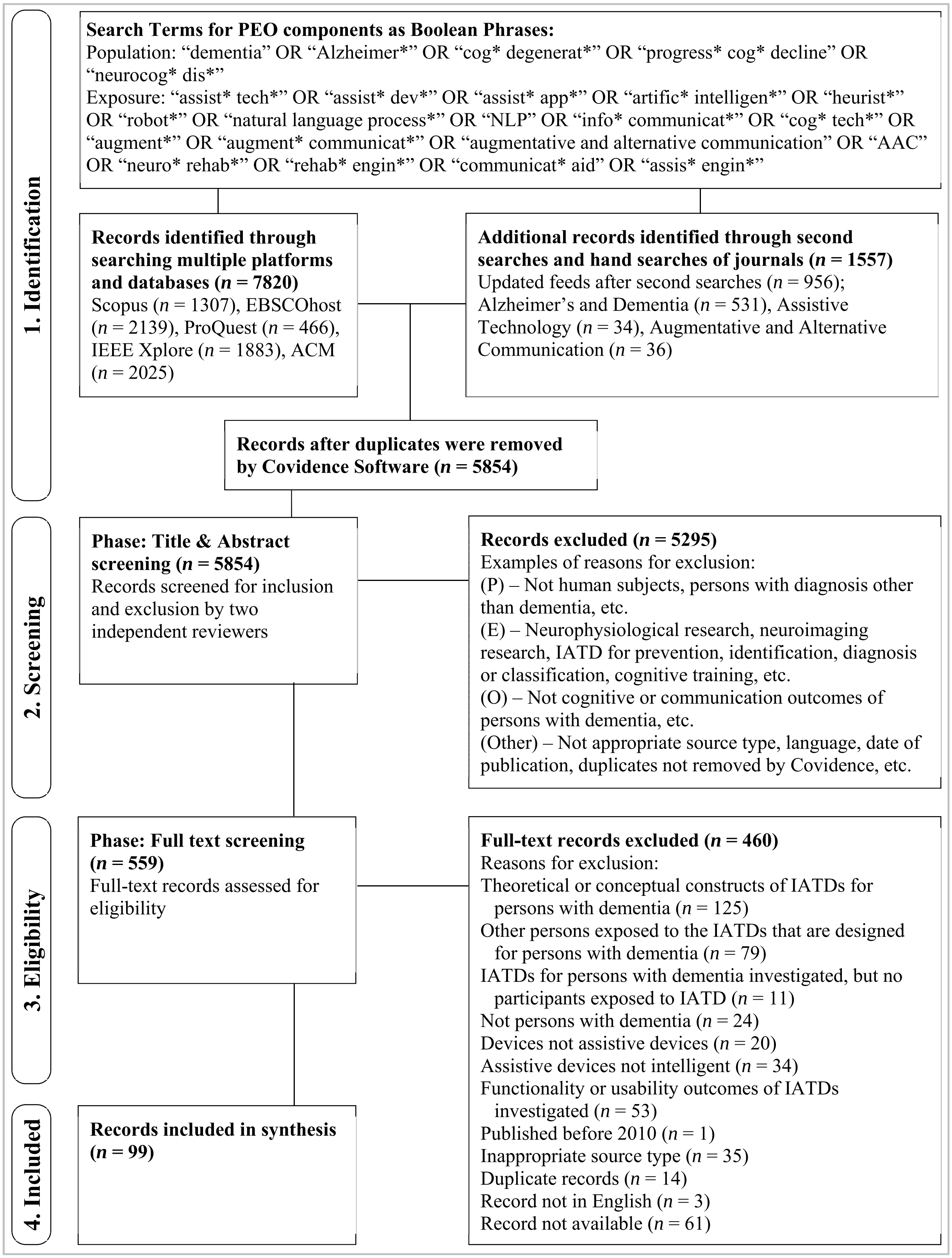

Figure 1. PRISMA flow diagram of selection process.

- EXPOSURE: Assistive technologies with artificial intelligence for cognitive and communicative impairments, thus IATDs that respond to the user's needs and adapts to changing environments (McMurray et al., 2017).
- OUTCOME: Results related to performance of any of the cognitive domains that experience decline due to dementia: Complex attention, executive function, learning and memory, language, perceptual-motor, or social cognition (APA, 2013). Other outcomes related to cognitive faculties such as memory, communication, orientation, reasoning and decision making (Ienca et al., 2017), and outcomes related to social and emotional faculties (Ienca et al., 2017).
- DESIGN: Quantitative experimental, quantitative non-experimental, qualitative, mixed method design (McMillan & Schumacher, 2014).
- RECORD TYPE: Primary/original research published as peer-reviewed journal articles, unpublished dissertations and theses, conference proceedings, conference abstracts available through the University of Pretoria Library and databases.
- TIME AND LANGUAGE: Published in English, publication dated 2010–2020.

Source selection

Additional records were identified through updated feeds and second searches of above electronic database platforms, single electronic databases and journals (n = 1557). Duplicates were removed and the records went through an initial screening based on the Population and Exposure elements of the eligibility criteria. A full-text screening identified the records that met all the eligibility criteria. Figure 1 illustrates the eligible records for data extraction (n = 99). Figure 1 also contains the numbers of excluded records, together with some reasons why these records were not eligible for inclusion.

The percentage of agreement between raters, namely interrater agreement (IRA), was measured at full-text screening level (McHugh, 2012). Disagreements between raters were discussed until agreement to either include or exclude the references had been reached. IRA was calculated as 98.6 %.

Data extraction and synthesis

Data extraction occurred through the categorisation and verbatim transcription of parameters from the included records. Transcribed data was sorted and charted according to key issues and themes based on the specific research sub-aims (Arksey & O'Malley, 2005). Categories and themes were then synthesised and interpreted. The prescribed PRISMA-ScS items of reporting were followed for transparent reporting (Tricco et al., 2018).

A strategy to enhance reliability of data extraction is verification by independent member checking (McMillan & Schumacher, 2014). A speech-language therapist with a Master's degree in AAC scrutinised the data extracted from 40% of the records, as deemed appropriate for interobserver or interrater agreement data in AAC (Schlosser, 2003). The above also contributed to internal validity of the review by minimising subjective bias, as personal opinions and beliefs could not influence the outcomes. The level of evidence and validity of a review is also regarded higher than individual studies (Schlosser & Raghavendra, 2009) and the prescribed PRISMA-ScS items of reporting are followed for transparent reporting (Tricco et al., 2018).

Results

Diagnostic and severity grouping of PwD

The results indicated that a quarter (n = 25, 25.3%) of the records involved participants with a mix of diagnoses. Some (n = 13, 13.1%) of these records also involved participants with dementia and participants with no cognitive impairment or mild cognitive impairment, and some (n = 12, 12.1%) of the records reported on persons with subgroups of dementia that did not fit the inclusion criteria. The majority of records (n = 76, 76.8%) did not specify with which subgroups of dementia the involved participants had been diagnosed.

Persons with mild dementia (n = 17, 17.2%) were more often the subject of investigation than those with moderate (n = 14, 14.1%) and severe (n = 10, 10.0%) stage dementia. Wider ranges of stages, such as mild to moderate or moderate to severe stage dementia, were reported by some (n = 28, 28.3%) of the records. Some records also included PwD of all severities, i.e. mild to severe dementia (n = 11, 11.1%). The subgroup of dementia diagnosis and the stage of dementia diagnosed in the PwD appear not to be recognised as important factors to investigate, as more than half of the records (n = 52, 52.5%) did not report on the severity of dementia of the study participants. It should be noted that the predominant fields of research that were identified emanated from engineering and technology databases.

Cognitive and communicative domains targeted by the IATDs

The results indicate that IATDs have been developed predominantly to address cognitive domains of impairment. These domains are complex attention, the ability to disengage and shift attention (n = 76, 72.4%), as well as emotion or affect (n = 77, 73.3%). An example is the RAMCIP robotic assistance device that provides support for activities and recognises emotions (Antona et al., 2019; Mahendra et al., 2018). Fewer of the IATDs that were examined assisted with executive function (n = 37, 35.2%), learning and memory (n = 20, 19.0%) and perceptual-motor difficulties (n = 11, 10.5%).

IATDs that address communication difficulties were mentioned less than those that address cognitive difficulties due to dementia. Some IATDs (n = 22, 21.0%) attend to receptive language difficulties by creating positive interactions (Chu, Khosla, Khaksar, & Nguyen, 2017). The PaPeRo social robot is another example of an IATD assisting with receptive language by providing information and prompts (Inoue et al., 2012). More IATDs (n = 33, 31.4%) address expressive language difficulties, such as Ryan Companionbot and other conversational social robots, which can interpret and react to the linguistic utterances and facial expressions of PwD (Abdollahi, Mollahosseini, Lane, & Mahoor, 2017). Few records (n = 7, 6.7%) reported on automatic communication functionality, where messages are sent to caregivers automatically, without being initiated by the PwD. The majority of the IATDs (n = 72, 68.6%) provided social-pragmatic skill assistance via companion social robots such as Pleo, CuDDler and PARO. These devices are autonomous robots with sensors interacting with artificial intelligence software, which enables the devices to respond to the environment and the user with its own movements, eye contact and responses to voice, thus taking turns and eye contact is prompted and reinforced (Hendrix, Feng, Van Otterdijk, & Barakova, 2019; Moyle et al., 2017, 2015).

Availability for purchase

This review further aimed to identify IATDs that are available for purchase to the public for the care of PwD. The results indicate that a large portion of the IATDs (n = 41, 38.7%) took the form of prototypes that were still under development and not

Table 1. Summary of Prototype IATDs

Reference:	Name of IATD	Name of off the shelf elements of IATD	Cognitive and communicative domains targeted by the IATD
Abdollahi et al. (2017)	Ryan Companionbot		COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Antona et al. (2019)	RAMCIP		COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Asghar (2018)	E-Community for Dementia (ECD) sofware application		COGNITION: Complex attention, Perceptual-motor
Bankole et al. (2011)	TEMPO 3		COGNITION: Emotion / Affect
Barreto et al. (2014)	Unnamed system	Arduino board (Uno), 3axis accelerometer (ADXL345), environment temperature and humidity sensor (HTU21D), DFRobot GPS/GPRS/GSM shield V3.0	COGNITION: Executive function COMMUNICATION: Expressive language
Bejan et al. (2018)	Unnamed system	software (Unity3D engine), 3D sensor (Microsoft Kinect), tracking device (Leap Motion), myoelectric bracelet (Myo)	COGNITION: Complex attention, Executive function, Learning and memory, Perceptual-motor COMMUNICATION: Social-pragmatic skills
Bennett et al. (2016)	Resonant Interface Rocking Chair, Story Panel Chairs probe, 'VR chair', TopoTiles	Mobile device (iPod Touch)	COGNITION: Complex attention, Executive function, Learning and memory, Emotion / Affect COMMUNICATION: Social-pragmatic skills
Bormans et al. (2016)	Mobile application (Virtual Memory Palaces)		COGNITION: Learning and memory, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills

Reference:	Name of IATD	Name of off the shelf elements of IATD	Cognitive and communicative domains targeted by the IATD
Chu et al. (2017)	Sophie/Jack		COGNITION: Complex attention, Executive function, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Cruz-Sandoval & Favela (2019)	Eva		COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Cruz-Sandoval & Favela (2017)	Eva		COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Cruz-Sandoval et al.(2018)	Eva		COGNITION: Complex attention, Executive function, Emotion / Affect COMMUNICATION: Expressive language, Social-pragmatic skills
Feng et al. (2019)	LiveNature, Interactive Robotic Sheep (Pleo robot using the Pleorb Development Kit (PrbDK))	Ultra-high resolution display (BenQ, 87'), computer (MSI Nightblade MI B089), custom-made Arduino enclosure (Arduino Uno with an extension board), infrared sensor (Sharp, 2D120XF95), electrical water pump (Easy Tpy 513-0214), water filter (Philips InstantTrust Marine), programming environment (Programming),	COGNITION: Complex attention, Executive function, Learning and memory, Perceptual-motor, Emotion / Affect COMMUNICATION: Social-pragmatic skills
Feng et al. (2018)	Closer to Nature	Custom-made Arduino enclosure, water filter (Philips InstantTrust Marine)	COGNITION: Complex attention, Executive function, Learning and memory, Perceptual-motor, Emotion / Affect COMMUNICATION: Social-pragmatic skills

Reference:	Name of IATD	Name of off the shelf elements of IATD	Cognitive and communicative domains targeted by the IATD
Gündogdu et al (2017)		Surface computer (40 inch Samsung SUR 40), Open Source application (reacTIVision), camera drivers (Linux IR), cross-platform game engine (Unity 3D), message application (Samplicator), plug-ins Unity Touch (Uniducial) and Marker-detection (Unity3d- tuio), IoT-based sensor framework (relayr Wunderbar), sensor data encoder application (relayr Java SDK)	COGNITION: Complex attention, Executive function, Perceptual-motor, Emotion / Affect COMMUNICATION: Social-pragmatic skills
Hartin et al. (2014)	Technology Adoption and Usage Tool (TAUT) app	Smartphone (LGE Nexus 4)	COGNITION: Learning and memory
Huang et al. (2019)	Unnamed devices and system		COGNITION: Executive function, Emotion / Affect COMMUNICATION: Expressive language
Kanno et al. (2019)		Smartphones (Asus Zenfone 2 Plus; Motorola G4 Plus)	COGNITION: Executive function, Learning and memory
Kashimoto et al. (2016)	Twinkle Megane		COGNITION: Executive function, Perceptual-motor
Khan et al. (2019)	Detection of Agitation and Aggression (DAAD) system		COGNITION: Complex attention, Emotion / Affect
Koldrack et al. (2015)	Unnamed system	GPS receiver (Qstarz Travel Recorder XT, BT747), three axes activity sensor (64 Hz Move II, from Movisens), electrodermal activity sensor (32Hz edaMove from Movisens), single channel electrocardiography sensor (256Hz ekgMove sensor from Movisens)	COGNITION: Complex attention, Executive function, Perceptual-motor
Lauriks et al. (2018)	Unnamed system		COGNITION: Executive function, Perceptual-motor COMMUNICATION: Expressive language

Reference:	Name of IATD	Name of off the shelf elements of IATD	Cognitive and communicative domains targeted by the IATD
Lazarou et al (2016)	Dem@Care FP7 project	Wristband (Jawbone UP24), IP camera (D-Link DCS-5020L), under-mat sleeping sensor (Withings Aura), smart plugs (Circle, Cirlce+, & Stealth by Plugwise.nl), smart tag accelerometers (Tags, PIR KumoSensor, Reed KumoSensor of the Wireless Sensor Tag System)	COGNITION: Executive function, Emotion / Affect
Ludden et al. (2019)	Unnamed virtual nature installation		COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Social-pragmatic skills
Lyu & Yuan (2020)	Unnamed system	Mobile devices, a Smart Dog, web applications, a cloud server, physiological sensors (motion sensor, smart watch, pulse oximeter, electroencephalography (EEG) sensor, and cardiopulmonary stethoscope)	COGNITION: Executive function, Emotion / Affect COMMUNICATION: Expressive language
Martin et al. (2013)	NOCTURNAL		COGNITION: Executive function, Learning and memory COMMUNICATION: Expressive language
Morel et al. (2015)	Memory Lane application		COGNITION: Learning and memory
Moyle et al. (2015)	CuDDler (Infocomm)	Two android smartphones	COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Social-pragmatic skills
Navarro et al. (2014)	AnswerBoard, AnswerPad		COGNITION: Executive function, Learning and memory, Emotion / Affect
Rostill et al. (2018)	Unnamed system		COGNITION: Executive function
Rudzicz et al. (2017)	Ludwig		COGNITION: Complex attention, Executive function COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Savita et al. (2018)	MyDem application		COGNITION: Learning and memory

Reference:	Name of IATD	Name of off the shelf elements of IATD	Cognitive and communicative domains targeted by the IATD
Seymour et al. (2017)	AMI (Adaptable Music Interface)		COGNITION: Complex attention, Emotion / Affect
Siriaraya & Ang (2014)	Unnamed system		COGNITION: Complex attention, Executive function, Perceptual-motor
Stavropoulos et al. (2016)	Dem@Care		COGNITION: Complex attention, Emotion / Affect
Tokunaga et al. (2016)	Memory-PAL (Memory-aid service with Personalization, Agent and Location technologies)		COGNITION: Complex attention, Executive function COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Wang et al. (2016)	Unnamed system		COGNITION: Executive function COMMUNICATION: Expressive language
Wang et al. (2010)	NOCTURAL system, FOLD telecare		COGNITION: Complex attention
Wargnier et al. (2018)	LOUISE (Lovely User Interface for Servicing Elders)		COGNITION: Complex attention, Executive function, Learning and memory COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills
Wolf et al. (2018)	cARE, HoloLens		COGNITION: Complex attention, Executive function, Learning and memory
Zmily & Abu-Saymeh (2013)	Adcope application	Smartphones running Google Android OS	COGNITION: Learning and memory

commercially available. Prototyping is necessary for researchers to develop, refine and assess human-computer interaction concepts and systems (Odom et al., 2016). Although prototyping is a positive outcome of an expanding human-computer interaction research field, prototypes are mere references or placeholders of future systems, services or products that are not yet available outside of the involved research settings (Odom et al., 2016). Table 1 provides identifying information of the included records that reported on prototype IATDs.

The majority of the IATDs (n = 45, 42.5%) were reported to be available to the public through online ordering. These products could be purchased via the respective manufacturers' websites, and many social robots were available for online ordering. The results, however, provide a skewed view of the availability of IATDs for PwD or their caregivers. The IATDs research field is dominated by research concerning PARO, the robotic seal pup. When the records that report solely on PARO (n = 29) were separated from the rest, significantly fewer records reported on other IATDs (n = 16) that were available through online ordering.

Furthermore, a total of eight (7.5%) of the IATDs were commercially available in retail. The research involving these IATDs often combined various off-the-shelf devices or used specific software to create IATDs for PwD. The devices rarely functioned as IATDs in isolation. The two remaining portions of IATDs examined in the collection of records were reported as only available for research purposes (n = 6, 5.7%) or as unknown (n = 6, 5.7%).

Table 2 provides a summary of IATDs that address cognitive and communicative areas for PwD and that are available in retail or via online ordering.

Table 2. Summary of Available IATDs

Cognitive and communicative domains targeted by IATD	Name of IATD or off-the-shelf devices	Sources included in scoping review
COGNITION: Learning and memory	Smartphone (Nexus 5 running Android OS v6.0.1.), smartwatch (Sony SmartWatch 3 running Android Wear)	Thorpe et al. (2019)
COGNITION: Complex attention, Executive function COMMUNICATION: Expressive language	Unnamed system	Wessel et al. (2019)
COGNITION: Executive function COMMUNICATION: Expressive language	Infrared motion sensors (Samsung SmartThings Motion Sensor), bed sensor (Ecolink DWZWAVE2-ECO with Ideal Security SK630 Pressure Mat), magnetic latch sensors	Wallace (2018)
COGNITION: Executive function	Basis B1 smartwatch	Boletsis et al. (2015)
COGNITION: Complex attention, Learning and memory, Emotion/Affect	Triple Point Sensor (TPS) (Thought Technology Ltd. ©) with Events Finder custom software, (a freely available MATLAB toolbox, https://github.com/BIAPT/Events-Finder)	Lai Kwan et al. (2019)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills	Ticket to Talk application	Welsh et al. (2018)
COGNITION: Complex attention, Executive function, Emotion/Affect	ABBY (Ambient Activity Technologies)	Wilkinson et al. (2018)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Social-pragmatic skills	FurReal Friends Lulu Cuddlin Kitty	Heerink et al. (2013)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Social-pragmatic skills	Guide Robot (ED Robotics Company)	Robinson et al. (2013)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills	MARIO	Kouroupetroglou et al. (2017)

Cognitive and communicative domains targeted by IATD	Name of IATD or off-the-shelf devices	Sources included in scoping review
COMMUNICATION: Expressive language, Social-pragmatic skills	NAO (SoftBank Robotics)	Delacroix et al. (2018) Demange et al. (2019) Fields et al. (2019) Valentí Soler et al. (2015)
COGNITION: Complex attention, Executive function, Learning and memory COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills	PaPeRo (Partner Personal Robot) (NEC Corporation)	Inoue et al. (2012)
COGNITION: Complex attention, Executive function, Learning and memory, Emotion/Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills	Pepper (Softbanks Robotics Pepper Robot)	De Kok et al. (2018)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Social-pragmatic skills	PLEO Robot - Camarasaurus (Innvo Labs)	Heerink et al. (2013) Hendrix et al. (2019) Perugia et al. (2017)
COGNITION: Complex attention, Emotion / Affect COMMUNICATION: Receptive language, Expressive language, Social-pragmatic skills	“Sota” communication robot; Intel RealSense Depth Camera D415	Iwabuchi et al. (2019)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Social-pragmatic skills	Sugar	Iacono & Marti (2016)
COGNITION: Complex attention, Emotion/Affect COMMUNICATION: Social-pragmatic skills	(unnamed robot cat)	Picking & Pike (2017)

COGNITION: Complex attention, Executive function, Emotion/Affect COMMUNICATION: Social-pragmatic skills	PARO (the Intelligent Systems Research Institute (ISRI));	Bemelmans et al. (2015) Bemelmans et al. (2016) Chang et al. (2013) Demange et al. (2018) Demange et al. (2019) Hung et al. (2019) Hung et al. (2019). Iacono & Marti (2016) Jones et al. (2018) Jøranson et al. (2015) Jøranson et al. (2016) Kawaguchi et al. (2010) Koh & Kang (2018) Liang et al. (2017) Moyle et al. (2013) Moyle et al. (2013) Moyle et al. (2017) Moyle et al. (2018) Moyle et al. (2018) Moyle et al. (2019) Moyle et al. (2019) Petersen et al. (2017) Pu et al. (2020) Robinson et al. (2013) Takayanagi et al. (2014) Thodberg et al. (2016) Valentí Soler et al. (2015) Yu et al. (2014) Yu et al. (2015)

Discussion

This review aimed to synthesise current research evidence of available IATDs applied to the impaired cognitive and communicative functions of PwD. It also focused on identifying trends and gaps in the evidence. In the studies reviewed, it is notable that the subgroup of dementia diagnosis and severity of communicative impairment in the PwD are often not specified in the research records. A reason for this could be that researchers in the computer science and engineering fields do not assign as much importance to these details as those who conduct research in the health and non-pharmacological intervention fields. The latter focus on cognitive and behavioural difficulties such as activity and communication impairments (Livingston et al., 2017). The unavailability of information regarding the subgroups and severity of dementia leads to difficulty in matching IATDs to PwD who might benefit from the devices. This correlates with recommendations of authors from included records that suggested that research should aim to examine IATD interaction of different user groups to determine patterns of outcomes in relation to severity of impairment (Hebesberger, Dondrup, Gisinger, & Hanheide, 2017; Heerink et al., 2013). The first trend was identified by the high number of records that were excluded at full-text level. The trend revealed that the field of IATDs for PwD is heavily dominated by research that has unfortunately not evaluated the devices developed for PwD with PwD. This does not align with the current interest in user-centered design of IATDs that follow the processes of analysing the needs of PwD, designing solutions according to information and communication technology design guidelines and then evaluating the solutions specifically with PwD (Ceccacci, Generosi, Giraldi, & Mengoni, 2017). The prospects of improving the lives of PwD with successfully implemented IATDs are well-reported (Ienca, Wangmo, Jotterand, Kressig, & Elger, 2018). However, in order to achieve this benefit for PwD their views and opinions, as well as those of relevant stakeholders, in the development stages of IATDs are crucial. The trend noted in this current review contributes to the recent discourse which advocates that technology designers should include PwD in the development of IATDs to assess prospective clinical and technical challenges (Ienca et al., 2018; Wangmo, Lipps, Kressig, & Ienca, 2019). Notwithstanding the benefits of involving PwD, designers should be mindful of the ethical challenges (e.g., informed consent for PwD) associated with the technological complexities of developing IATDs with PwD (Wangmo et al., 2019).

Furthermore, the review indicates a paucity of research underpinned by intervention theory or the interpretation of results from a theoretical framework. In fact, a recurrent theme in reviews of IATDs, including social robots, is a distinct paucity of research grounded in intervention theory. Accordingly, there is insufficient mapping of IATD features onto measurable outcomes, particularly those related to psychosocial outcomes for PwD. As such, factors contributing to the acceptance and adoption of such technologies by PwD and their caregivers remain poorly understood.

Moreover, the review highlighted that much of the research has not assessed the cognitive and communicative outcomes of PwD following implementation of an IATD. This further emphasises a need to include PwD as research participants of IATDs studies. In doing so, and as aligned with evidence-based practice, this will ensure that the perspectives of PwD are included in the assessment of social validity, and in determining measurable cognitive and communicative outcomes of these interventions (Schlosser & Raghavendra, 2003). Lastly, it is noteworthy that a weakness in the reviewed literature is a distinct lack of reported efficacy studies.

Where cognitive and communicative domains were considered the records eligible for inclusion demonstrated that a large proportion of evidence in the field is concerned with the cognitive areas of attention and emotion/affect. Communicative areas are addressed less. Within communication areas, social robots for PwD – especially PARO – form a definite trend. The review also showed how little attention is given to research intelligent AAC communication devices for PwD, even though communication difficulties form a substantial part of the symptoms experienced by PwD.

Additionally, this review endeavoured to report on the availability of IATDs for PwD or their caregivers. It seems that IATDs are not easily accessible to the public, as many are only prototypes under research, and are, therefore, not yet available outside of the involved research settings. Furthermore, those IATDs that are available for ordering are costly and prohibitive. Although authors reported many limitations of IATDs due to their early phase of development, the review showed that this field is filled with potential for future IATDs for PwD.

Conclusion

The strengths of this review lie in its scope and in the types of sources from the computer engineering as well as medical research fields that were used to collect eligible records.

Limitations of this review include the possibility of reviewer bias, although reviewers were blinded to each other's inclusion or exclusion votes. Unfortunately, linguistic and access bias also played a role, as only English records available through the University of Pretoria's library were included. Another limitation was posed by the fact that some records (n = 61) could not be accessed for the eligibility process.

Technological advances such as adaptable, context-aware and artificially intelligent computing have opened up many possibilities for non-pharmacological treatment of the impairments experienced by PwD. The bulk of research focused on social robots to address interaction, leisure and social-pragmatic communication skills of the PwD, and especially featured the PARO seal pup robot. Furthermore, prototypes featuring in the research detailed here have not yet progressed to commercially available products, thus limiting their potential for clinical use. As communication difficulties are prevalent in PwD, IATDs for AAC purposes and outcomes also require further development and research.

Translating research evidence into practice requires dissemination of information, policy considerations and workforce training (Gitlin, Marx, Stanley, & Hodgson, 2015). The outcomes of this scoping review can therefore inform clinicians or caregivers of PwD who are exploring IATD procurement, and the outcomes might be used in policy or training development. Information about the IATDs mentioned in this review that are available for purchase or ordering appears in Table 2 to assist informed decision making.

It is highly recommended that future research regarding cognitive and communicative IATDs (including AAC devices) for PwD should focus on developing technology and involve these persons as collaborators and participants in research studies (Moulam, Meredith, Whittle, Lynch, & Murray, 2020). The subsequent cognitive and communicative outcomes should be evaluated to contribute to evidence-based decision making and practice (Schlosser & Raghavendra, 2009). Populations falling under the umbrella term of dementia diagnoses should be specified to identify outcome patterns more explicitly. Furthermore, the development of intelligent communication devices could benefit from additional focus on receptive and expressive language abilities to assist PwD to communicate with familiar and unfamiliar persons, and not only to enhance social-pragmatic skills as indicated by this research.

The review found that research concerning social robots other than PARO, other types of IATDs and IATDs with other functions, especially communication, is limited. Evidence-based decision making regarding AAC technology will further benefit from research that investigates natural language processing and its applications for different areas of communicative impairment.

Lastly, this review recommends increased research collaboration between computer engineering and health practitioners. The collated evidence will be greatly beneficial for clinical application and for advancement from a prototypical stage to commercial availability.

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