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Understanding the research landscape of information and communication technology integration in dementia-focused assistive technologies: Mining literature from 1970 to 2020

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Abstract

Background: As our society gets older, the implications of information and communication technologies (ICT)-based healthcare have increased. Although the adoption of ICTs has dramatically changed the landscape of the health sector since the early 1950s, the benefits that ICTs could bring to dementia care have been relatively unexplored.
Objective: This paper mined the research articles for insights into how relationships between ICTs and assistive technologies (ATs) in dementia care have been developed historically and should be cultivated in the future.
Method: Using text-mining techniques, 2,030 journal articles regarding ATs in relation to ICTs in dementia care published from 1970 to 2020 were analyzed. The literature was retrieved from the Web of Science, PubMed, PsycINFO, and IEEE Xplore digital library.
Results: Despite the active integration of ICTs in many other sectors, the literature demonstrated that research regarding ICT integration in ATs for dementia interventions occurred only after the 1990s. The analysis results also indicate that studies have moved toward supporting the aging-in-place of people with dementia, encompassing major research interests such as assisting with daily activities of living, modifying the home, and promoting recreational activities. A research gap was also identified in technology adoption to support the social interactions of those with dementia, which is a key part of enhancing the quality of life.
Conclusion: The research that addressed ICT integration with ATs for dementia care has been evolving and moving from issues of safety and security to maintaining autonomy of people with dementia in their own place.

Keywords: information and communication technology, health informatics, literature analysis, assistive technology, dementia

Introduction

Information and communication technologies (ICTs) have been recognized as a highly satisfactory method of delivering treatment, patient assistance, or interventions for people with long-term health conditions in a cost-effective manner (Gentili, et al., 2022). The widespread adoption of ICTs has unveiled new opportunities to enhance the efficacy, quality, and effectiveness of the healthcare and introduce novel and reinvented applications (Aceto et al., 2018).

Implications of ICT-based healthcare increase when it comes to healthcare for the aging population with chronic conditions including dementia (Astell et al., 2019; Sixsmith, 2013; World Dementia Council, 2018). The constant growth of the population of people with dementia (PwD) creates higher demands in healthcare and the need for new and more advanced solutions (Basham et al., 2020). The proportion of older adults in the population is increasing and incidences of dementia increased exponentially with age. Dementia has a wide range of physical, psychological, social, and economic impacts, not only for PwD but also for their caregivers. The fact that no significant breakthrough is currently available in pharmacological treatment or intervention for dementia increases the potential for ICT-based, dementia-dedicated devices, applications, and services to optimize the functioning of PwD and benefit their caregivers (Astell et al., 2019).

However, PwD are viewed as a sub-population in our society that is missing out on this technological explosion in healthcare (Astell, 2009;

Mountain, 2013). This can be attributed mainly to the commonly held but arguably incorrect assumption that the benefits of ICTs for PwD are likely to be limited in comparison to the rest of the population or even among aging groups due to the unique symptoms of dementia (e.g., memory loss, problems with judgment) (Sixsmith, 2013). Despite this assumption, efforts have been made to facilitate devices, products, services, or applications with ICT elements to meet the needs of PwD and their caregivers. However, relatively little effort has been made to understand how ICT-based assistive technologies (ATs) could promote interventions for PwD. Studies regarding ICTs, ATs, and dementia intervention are separate rather than providing a holistic understanding of how ICTs have been applied to and integrated with ATs and how these ATs are used for interventions. Previous reviews mainly focused on types of ICTs, ATs, or interventions in dementia care. These reviews provided an in-depth understanding of the types of ATs or interventions, but they left unclear how ICTs, ATs, and interventions are interrelated in dementia care.

Thus, this study aims to provide a holistic research landscape on how ICTs have been integrated with ATs historically to support dementia care and should be cultivated in the future. Particularly this study looks for assisting researchers who are interested in connecting ICTs with ATs development for PwD or their caregivers. To do so, researchers in dementia care or ICTs must be able to connect with research fields outside their core competence. However, due to the growing number of publications at a considerable rate, it became challenging for a researcher to keep up-to-date with all the relevant literature manually. Recently literature-mining tools became available, enabling researchers to extract information from scaled published articles and have researchers connected with research outside of their areas of expertise (Feng, et al., 2017). Thus, to analyze scientific literature published in five decades, this study applied text-mining techniques to provide a holistic overview of the implementation of ICTs to dementia-focused ATs. This paper can contribute to providing an understanding of the state of the art in this area, guiding the interested readership through the landscapes generated when new or advanced ICTs are adopted in dementia-focused ATs.

Background

Assistive technologies in dementia care

Dementia is one of the most common conditions and a major cause of disability and dependence for people aged 65 or older (Centers for Disease Control and Prevention, 2020; World Health Organization [WHO], 2020). Dementia refers to a group of neurodegenerative brain disorders (WHO, 2020), characterized by progressive cognitive impairment often accompanied by neuropsychological symptoms (e.g., depression, anxiety, and agitation). These conditions undermine mental and physical functions, including activities of daily living (ADLs) such as eating, cooking, and bathing (National Collaborating Centre for Mental Health [NCCMH], 2007). The conditions also increase the risk of dangerous actions such as falls and unsafe wandering that lead to the use of physical restraints to prevent injury (WHO, 2020). Consequently, as the disease progresses, the level of required care, assistance, and monitoring for PwD increases in many aspects, including daily activities, medical care, and safety. Nursing home care can be an option, but many older adults prefer to stay in their own homes or cannot afford to move into residential care for financial reasons or lack of services (Evans et al., 2015). This situation increases PwD's dependence on their caregivers. This can be overwhelming and costly for their caregivers and society. The direct and indirect costs of caring for people with Alzheimer's disease alone in the United States were $268 billion in 2010 (Deb et al., 2017). As the number of PwD is expected to rise to 130 million by 2050 from 54 million in 2040 (WHO, 2020), the costs of care are forecasted to reach $259 billion by 2040 (Deb et al., 2017).

In response to this situation, there has been continuous interest in developing and maturing ATs to facilitate sustainable wellness of PwD (Alwin et al., 2013; Fleming & Sum, 2014; Kaye, 2017; Tran, 2014; Van der Roest et al., 2017). AT was first defined in the Technology-Related Assistance to Individuals with Disabilities Act of 1988 (Tech Act) as "any item, piece of equipment, or product system … that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" (Public Law 100-407, Sec.3 1988). More recently with a growing number of aging populations, WHO established the Global Cooperation on Assistive Technology (GATE) to facilitate activities, inclusion, and participation in society. To remain independent, access to ATs is becoming as important as access to any other medical product (Salomon et al., 2012) GATE defines AT systems as "the development and application of organized knowledge, skills, procedures, and policies relevant to the provision, use, and assessment of assistive products" (Khasnabis et al., 2015, p. 1). Assistive products include any product such as devices, equipment, and software whose primary purpose is to maintain or improve a person's well-being by helping functioning and independence (Khasnabis et al., 2015). For PwD, ATs have been developed and evolved in increasingly sophisticated ways to meet the challenges in daily living that arise from symptoms associated with dementia by incorporating old and new technologies, such as telephone monitoring, memory aids in the form of reminders, and domestic robots (Jøranson, 2020; Lauriks et al., 2007; Persson, 2020; Song et al., 2018).

The merits of ATs in this area are evident both for individuals and society. For PwD, ATs have developed and progressively matured in a way that provides safety, security, supporting cognitive and physical functionalities, and social participation, which have considerable potential for enhancing the quality of life and "aging in place" of PwD (Farrugia, 2021; Sixsmith, 2013). Assistance from ATs enables both PwD and their caregivers to carry out tasks in their daily lives, monitor safety, and access healthcare that they otherwise would not be able to do more easily and safely more easily and safely (Chernbumroong et al., 2013). The use of ATs also helps PwD have more confidence and positive effects, thereby indirectly reducing caregiver burden (Lauriks et al., 2007). For society, hosts of ATs that are designed to improve the quality of care and lives of PwD and their caregivers can save both direct and indirect societal costs. To illustrate, a one-month delay in the use of institutional care for all adults aged 65 or older can save $1.2 billion in annual health expenditures in the United States alone and avoid an additional $46 billion (1991 value) in indirect costs such as time and opportunity costs and extra medical costs for caregivers (Gallotti et al., 2020).

ICTs in healthcare and implications for people with dementia

After discussion started about how to use computer technology in medication practice in the early 1950s, the adoption of ICTs dramatically changed the landscape of the health sector, and ICTs have grown to play a crucial role in the health delivery systems (Aceto et al., 2018; del Carmen Ortega-Navas, 2017; Reid et al., 2005). ICT is an umbrella term without a universal definition that covers "the set of technologies developed to manage information and send it from one place to another" (Sharief, 2019, p1). The most important technical change in electronics was digitalization, which refers to a process of converting signals from an analog to a digital medium (Wallace, 1997). Digitalization enabled healthcare information to be transformed into different formats (e.g., audio, video, animation, text and graphics, and sound), and transmitted in an interactive manner (Barton & Dexter, 2020). This enables the provision of information and emotional support for caregivers and easier access for healthcare professionals to patients (Czaja et al., 2013; Lauriks et al., 2007). As such, advancements in ICT presents a strong potential to provide value-added and patient-centered services and empower patients to take an active role in health self-management (Aceto et al., 2018; Czaja et al., 2013).

The integration of ICTs in healthcare, in fact, has brought fundamental changes to healthcare paradigms such as e-health, mobile health, and ubiquitous health (Aceto et al., 2018). The e-health paradigm, for instance, broadly refers to the application of the Internet and other related ICTs that deliver health services and information, helping an individual with accessing health information, guidance, or support on health issues (Kodali et al., 2015). In the mobile health or m-health paradigm, patients receive direct access to health services regardless of time and place (Aceto et al., 2018). The Internet of things (IoT) enables distributed devices that are equipped with sensors, microcontrollers, and transceivers to aggregate, analyze, and communicate medical information over the Internet (Kodali et al., 2015). The features of IoT support personalized healthcare by combining an individual's biological, behavioral, and cultural characteristics together with patient support (Kodali et al., 2015). ICT advances have supported such a paradigm shift in the health sector.

Advances in ICTs created new possibilities to bring about significant benefits for not only general healthcare but also for older adults (Aceto et al., 2018; Sixsmith, 2013). The implications of ICTs' adoption in healthcare are, in fact, greater for older adults because the probability of developing chronic disease and the need for healthcare grow with age (Czaja et al., 2013). For instance, ambient assisted living utilizes a pervasive ICT system that integrates sensors, actuators, smart interfaces, artificial intelligence (AI), and communication networks to provide a supportive environment (Cavallo et al., 2015). These ICTs present the potential to enhance independence and well-being (Sixsmith, 2013), expanding the role of ATs from safety and security to supporting the independence of older adults, including PwD (Sixsmith, 2013).

Marked changes occurring in healthcare systems with an array of ATs with ICT elements offer a new environment for PwD and their caregivers for the management of their well-being and active aging (Czaja et al., 2013; Sixsmith, 2013). The potential of ICTs for PwD is, however, relatively unexplored because dementia was historically marginalized by a lack of investment in services for dementia diagnosis, treatment, and care (Waldemar et al., 2007). Besides, although a wide range of ATs has become available to address challenges from physical conditions related to aging, few previous studies provided a holistic view of how ICTs have influenced ATs for dementia interventions. Some reviews explored ATs for dementia (e.g., Persson, 2020; Vollmer Dahlke

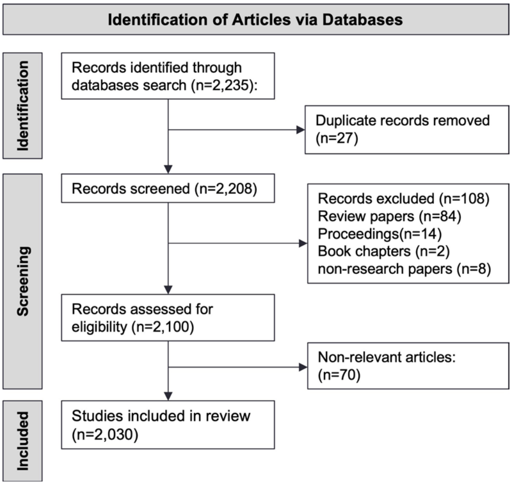

Figure 1. A flow diagram depicting the process of the study selection

& Ory, 2020) and interventions using ATs (e.g., Brims & Oliver, 2019; Klimova et al., 2018) for PwD or their caregivers. These studies provided an in-depth understanding of a specific type of AT, such as social robots (Jøranson, 2020), mobile technology (Koo & Vizer, 2019), and virtual reality (D'Cunha et al., 2019), or particular interventions such as supporting living environments (Daly Lynn et al., 2019), safety (Brims & Oliver, 2019), and memory support (King & Dwan, 2019; Van der Roest et al., 2017). But they left unclear which ICTs have been examined in relation to which ATs and interventions in dementia care.

The provision of impartial information on ICT integration with ATs in dementia care to date would enhance our ability to find optimal or new solutions for stakeholders, such as PwD, caregivers, healthcare providers, AT suppliers, researchers, and developers. To the best of our knowledge, few literature analyses have provided a broad historical overview of how ICTs have been applied to ATs in dementia care. Thus, this paper aims to provide an overview of what types of ICTs, ATs, and interventions have been discussed in the context of dementia care based on a comprehensive analysis of the literature published in the last five decades with the following research questions:
RQ 1. What types of ICTs, ATs, and interventions have been studied in dementia care by decade?
RQ 2. How are those ICTs, ATs, and interventions interrelated in dementia care?

Method

Search strategy and criteria

In this study, we focused on journal articles relevant to both ICT and dementia care that met the following inclusion criteria:

- Published between 1950 and 2020, because ICTs started playing a major role in healthcare at the beginning of the 1950s (Ambinder, 2005; del Carmen Ortega-Navas, 2017)
- Original research articles published in peer-reviewed journals in English, excluding bibliographies of original articles, book chapters, review papers, conference proceedings, opinion articles, letters to editors, commentaries, and non-English articles in order to focus on research progress in the areas of interest.

The authors of this study located articles from four databases: Web of Science, PubMed, PsycINFO, and IEEE Xplore digital library. Search strategies, search terms selection, and relevance of the initial search results were discussed by the authors until they reached an agreement. To decide the search terms, the authors also referenced MeSH terms and their trees. A combination of the general keywords "dementia," "dementia*," or "Alzheimer*" and their synonyms (e.g., information technology, ICT, Alzheimer, amentia, etc.) were used together with "information technology*" or "ICT." These search terms were combined using Boolean operators "AND" and "OR." Wildcards were also used to avoid being limited by lexical variations. To illustrate, the search term "technology*" AND "dementia" OR "Alzheimer*" and its synonyms were used to search titles, abstracts, metadata, all text, smart search, and/or subject headings. This query logic and terms were adapted to the language, search fields, and filters used by each database. Using filters of each database, the search results were refined to peer-reviewed journal articles that have abstracts and are written in English. We applied these restrictions because text mining requires sufficient texts that represent the main articles.

Dataset and analysis

The search identified 2,030 journal articles for analysis. The initial search yielded 2,235 hits from the four databases, but we removed duplicate articles (n = 27), review papers (n = 84), proceedings (n = 14), book chapters (n = 2), and non-research papers (n = 8) such as Q&As, indexes, and editorials. The authors of the study also reviewed the titles and abstracts of the yielded articles and filtered out 70 irrelevant articles (*Figure 1*). Although we searched articles published between 1950 and 2020, there was no literature published during the 1950s and 1960s was yielded.

Text-mining techniques were employed to analyze the titles and abstracts of the identified literature. Text mining is a computer-assisted data analysis method to process textual data at scale. Text mining has recently started being utilized for literature reviews with analytic techniques such as identification of relevant studies, categorization, summarization, and visualization (Malheiros et al., 2007; O'Mara-Eves et al., 2015; Thomas et al., 2011). Text mining enables researchers to

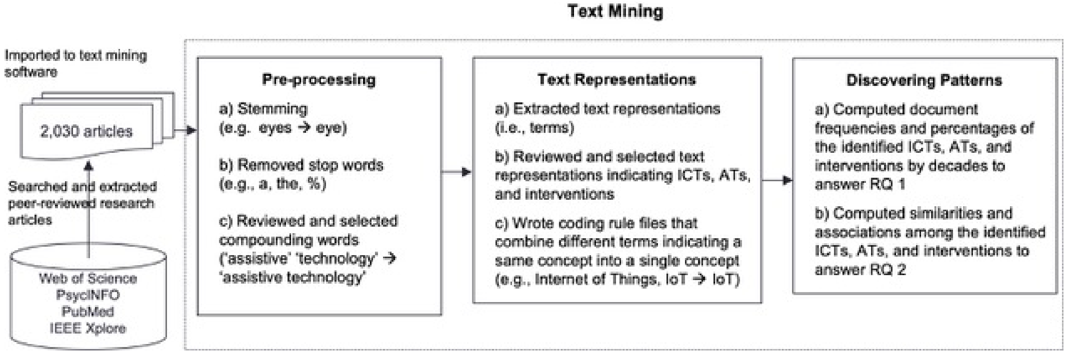

Figure 2. Analytic pipeline

discover previously unknown patterns in a textual dataset, utilizing statistical pattern-learning techniques (Hotho et al., 2005). For this study, text mining allowed the authors to analyze the collected literature that was published over five decades, and uncover the historical research trends and application of ICTs in dementia care, which would be time-consuming or difficult to discover through manual analysis.

Analyses of the collected literature were carried out corresponding to three general text analytic phases: pre-processing, extracting text representation, and knowledge discovery. In the pre-processing phase, (a) stop words (e.g., "ß," "%," and "of") and generic words (e.g., "abstract," "i.e.," and "ago") were removed. These words are known to hamper the effectiveness of text mining (Vijayarani et al., 2015) (b) terms were stemmed to their original form to reduce different grammatical forms or words word forms (e.g., "saying" to "say"); and (c) selected compound terms (e.g., "old adults," "assistive technology," and "decision support system") were reviewed and extracted as a single term to derive more meaningful text representations. Pre-processing in text mining is to help the effectiveness of text mining by reducing noise in data to extract more meaningful information from a dataset (Vijayarani et al., 2015) (*Figure 2*).

In the following phase, text representations were extracted, resulting in 21,376 terms, including those representing major ICT categories (e.g., "mobile computing," "IoT," and "3D printing"), types of ATs (e.g., "wheelchair," "monitor," and "hearing aids"), and types of intervention (e.g., "art therapy," "home modification," and "respite"). See Appendix A for the categories and definitions. Synonyms, abbreviations, and substrings that represent the same type of ICT, AT, or intervention were merged as a single text representation. For instance, "internet of things" and "IoT" were merged into a single term "IoT." The level of analysis in this study was concepts that represent categories of ICTs, ATs, and interventions. We developed codes that merge different terms, synonyms, abbreviations, and substrings that indicate the same concept or category. For example, the "mobile technology" category includes terms such as "mHealth," "mobile computing," etc. Codes were developed to merge the different terms into a single concept and computed the unique number of articles that contain those terms. Since we used document frequency (explained below), even if an article contains more than a single similar term, it was counted as one.

To identify text representations that represent topics of interest from the initially extracted terms, the following references were used: To identify terms that indicate major ICT categories adopted in healthcare, Aceto et al.'s (2018) article was referenced. Aceto and his colleagues identified major ICT categories that were adopted in the healthcare domain. Although these are identified as major ICT categories, some have no standard scientific definition. To better guide readers of this article, we provide brief definitions and descriptions of ICT categories addressed in this study in Appendix A. For intervention types, the Dementia Care Interventions List by the Agency for Healthcare Research and Quality (2020) and Santaguida and his colleagues' (2004) study were referenced. For ATs, AbleData categories (AbleData, 2020) were mainly referenced. Additionally, the National Institutes of Health webpage (National Institute of Health [NIH], 2020) and Bharucha et al.'s (2009) research were also referenced to include dementia-oriented ATs.

The researchers reviewed the sentences in which extracted terms appeared to understand the use of the individual terms. To illustrate, when an AT was used for multiple purposes, the same AT was classified into multiple categories. For instance, "motion sensor" was categorized into "safety and security aids" and "therapeutic aids" based on the context in which the term appeared. Hierarchical relationships among the identified terms were ignored because text mining assumes that if there is a text representation, it is regarded as an appearance of the concept in a dataset. In this study, therefore, an umbrella term that covered more than one type of ICT, AT, or intervention was regarded as an independent representation of the research topic. Individual codes were developed for ICTs, ATs, and interventions and imported to text-mining software, KH Coder3 (Higuchi, 2020), to compute the distributions and proportion of research and explore associations.

In the last phase, the amount of research and associations among topics of interest (i.e., ICTs, AT, and interventions) were examined using document frequency (df) and associations among the identified categories of ICTs, ATs, and interventions. Document frequency refers to the number of unique documents containing individual terms. In this study, this index indicates how many articles regarded individual categories of ICTs, ATs, and interventions. Thus, study productivity or the amount of research performed was examined using df by decade to investigate research trends regarding the topics of interest. The associations of individual categories, which are groups of terms, representing ICTs, ATs, and interventions, were computed to understand which ICTs were adopted with what ATs and what types of ATs were used in which dementia interventions. The following techniques and indexes were used to calculate the associations. The co-occurrence network analysis technique was used to discover unknown relationships among terms regarding types of ICTs, ATs, and interventions. This technique detects associations by assessing how frequently the paired terms co-occur in the same article (Wachs-Lopes & Rodrigues, 2016). The degree of co-occurrence Jaccard coefficient (Jc) (1901) was used. In the current study, Jc evaluates the degree of similarity between paired categories, or network edges, based on the frequency of co-occurrence of those terms in the same article. The value 1 indicates the strongest association, whereas 0 indicates no relationship (Milligan, 1985). In the current study, the paired categories were interpreted as the adoption or integration of a category into another. For instance, if an association emerged between an ICT category and an AT type, it is interpreted as the ICT was studied in relation to the type of AT. Additionally, to detect sub-groups of the ICTs, ATs, and intervention categories, we adopted modularity developed by Clauset, et al (2004). Modularity is a property of a network and a particular division of that network (Newman & Girvan, 2004) (*Figure 2*).

Results

The amount of studies regarding ICTs, ATs, and interventions in dementia care by decade

To understand the progress of research in the areas of interest, the distribution of the unique number of articles that contain the terms regarding the categories of ICTs, ATs, and interventions was examined by decade. Studies discussing ICTs in relation to ATs for dementia started in the 1990s but were limited to big data and only four AT types (i.e., safety and security devices, therapeutic aids, daily living aids, and communication aids). In the 2000s, the proportion of articles regarding ATs and interventions in relation to dementia grew to 32%, whereas that of ICTs stayed relatively low (16.6%). The proportion of articles addressing ICTs, however, quickly caught up. The following subsections further illustrate the research trends.

Studies regarding ICTs in relation to dementia care

From the collected literature, 13 types of ICT categories were identified. Big data was most commonly found, appearing in 155 articles (7.63%). It was closely followed by Wireless Body Area Network (WBAN) (df = 143, 7.04%), wearable technology (df = 88, 4.33%), smart technology (df = 80, 3.94%), and robotics (df = 64, 3.15%). Studies addressing ICTs first appeared in the 1990s but only in three articles that dealt with big data alone. The number of studies involving ICTs grew from 56 in the 2000s to 511 in the 2010s, surging from 16.6% in the 2000s and 39.3% in the 2010s. In 2020 alone, 177 articles were found to discuss ICTs in relation to dementia. It is 60.2% of relevant publications in the year 2020 alone. The proportions of articles about big data, wearable devices, WBAN, and smart technology underwent dramatic growth. To illustrate, a sudden interest in big data occurred recently, appearing in 1.48% (df = 5) of articles in the 2000s, 6.93% (df = 90) in the 2010s, and 19.39% (df = 57) in 2020. The finding indicates research started adopting the data-driven approach in relation to dementia care recently. Similarly, the proportion of articles about WBAN grew from 4.15% (df = 14) in the 2000s to 8.08% (df = 105) in the 2010s. Social and interactive media, contrastingly, was the least studied, appearing only in two articles (0.1%).

Studies regarding ATs in dementia care

Ten types of ATs were identified in the collected literature. Of those, safety and security devices were found to be the most commonly studied AT type (df = 282, 13.88%), followed by therapeutic aids (df = 175, 8.62%), daily living aids (df =102, 5.02%), and environment adaptations (df = 92, 4.53%). Articles concerning these three types of ATs were identified as early as the 1990s along together with communication aids, whereas other topics were not discussed until later. Studies regarding these types of ATs have increased relatively larger portions. This result indicates research interest regarding the three types of aids started earlier and become a main-

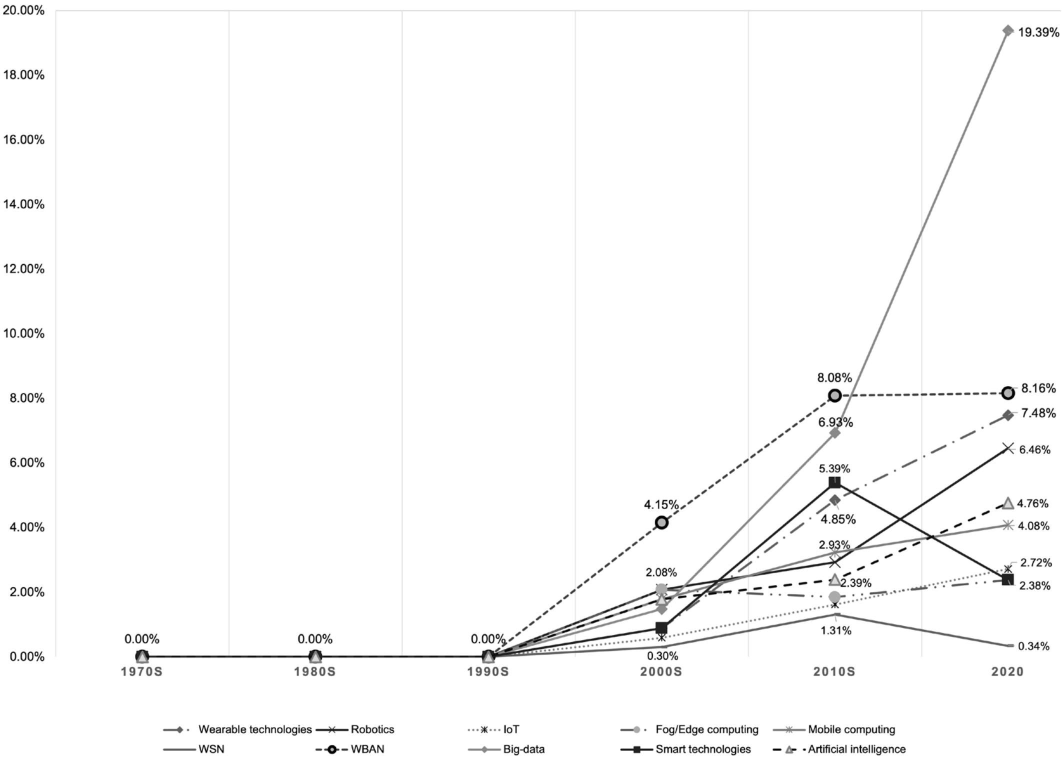

Figure 3. Percentage distribution of articles over the top 10 most frequently identified ICT categories per decade from 1970 and 2020

stream focus in the studies that utilized ICTs to dementia-focused ATs. Particularly, researchers' interest in safety and security aids has soared, accounting for over 15% of publications in the 2000s. Research interest in therapeutic aids has also gradually increased, accounting for approximately 5.95% of publications in the 2000s to 9.47% in 2010, then to 10.54% in 2020 alone. Studies about daily living aids also increased from 1.48% in the 2000s to 5.62% in the 2010s, then to 7.82% in 2020. On the other hand, the proportion of publications about communication aids slightly decreased from 5.95% in the 2000s to 4.39% in the 2010s.

Studies regarding dementia interventions

Analyses identified 37 intervention types in the dataset. Caregiver support interventions were the most studied, appearing in 129 articles (6.35%). They were followed by physical environmental modifications (df = 83, 4.09%), cognitive behavior therapy (df = 63, 3.10%), and sensory-based interventions (df = 53, 2.61%). As with ATs, a surge of interest in diverse intervention types was observed since the 2000s. In other words, only since the 2000s, have relatively more diverse types of intervention started being discussed in the studies that integrated ICTs into ATs in dementia care. Twenty-two types of interventions (59.5% out of 37) were found in the 2000s, appearing in many more articles (df = 102), whereas slightly over 20% of the identified intervention types (n =8, 21.6% out of 37, df=22) were found in the 1990s. See Appendix B for the distribution and proportion of articles that contain the regarded topics. *Figures 3*, *4*, and *5* visually present the changes in the proportions of articles by decade.

Associations among topologies of ICTs, ATs, and interventions in dementia care

Co-occurrence between the regarded categories was examined to understand what ICTs were studied in relation to ATs for dementia interventions. When examining the number of associations, smart technologies, WBAN, and robotics were found to be associated with eight types of AT, which is the largest number of ATs (n=9 out of 10, 90%). This indicates these three types of ICTs have been most widely adopted in ATs. They were followed by mobile computing and wearable technologies (n=8 out of 10, 80%). In contrast, social and interactive media technology and 3D printing were the least adopted, associated with only three types of ATs with weak similarity scores of .01 or .02. Although the number of articles regarding big data (df = 155) increased significantly during the 2000s and 2010s, big data technology was found to be associated with a relatively smaller number of ATs (n=6,

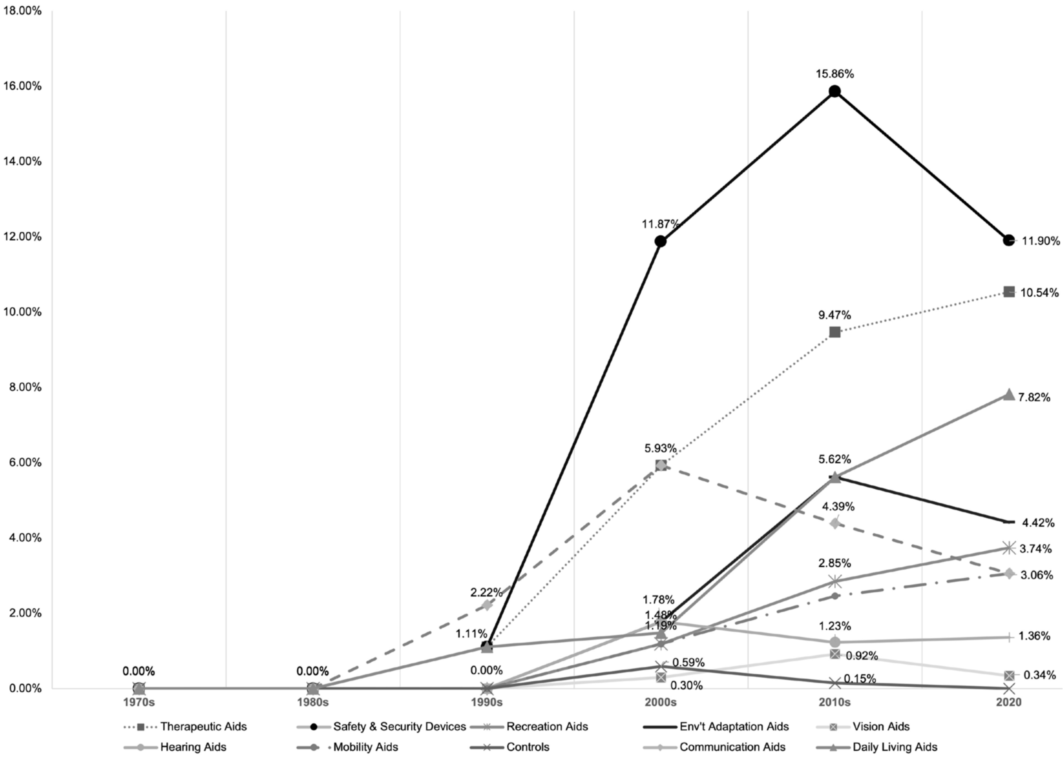

Figure 4. Percentage distribution of articles over the top 10 most frequently identified AT categories per decade from 1970 and 2020

60%). On the other hand, although the numbers of articles about robotics (df = 64) and wearable technologies (df = 80) were relatively small, these ICTs were found to be studied in relation to relatively more diverse ATs: Robotics was associated with nine types of ATs and wearable technologies was associated with eight types of ATs.

The similarity scores were also examined to understand how actively ICTs were utilized to develop ATs. Smart technology showed the strongest relationship with environment adaptation (Jc = .39), followed by IoT (Jc = .24). IoT also showed a relatively stronger association with daily living aids (Jc = .20). These results indicate that smart technologies and network of interconnected computing systems over the Internet have been actively adopted to change or improve physical environments in a way that better supports PwD's daily lives (*Figure 6*). WBAN was found to have relatively stronger associations with safety and security devices (Jc = .21), daily living aids (Jc = .16), and mobility aids (Jc = .14). A similar associative pattern was found with wearable technology. These results suggest that ATs for mobility and safety and security issues in daily life are equipped with and interfaced with sensors that can be attached to or implanted in the body or wearable sensing devices that are capable of monitoring PwD's activities. In other words, these ICTs have been actively adopted in developing ATs that focus on securing the safety and security issues of PwD. Although robotics was found to be associated with most of the identified ATs (n = 9, 90%), unlike other ICTs, it showed a relatively stronger association with recreation aids only (Jc = .17) (*Table 1*).

To understand for which type of interventions the identified ATs were utilized, the associations between interventions and ATs were explored. Therapeutic aids were associated with the largest number of intervention types (n = 27, 73% out of 37). This indicates that therapeutic aids have been utilized in the most diverse types of interventions. It was followed by safety and security devices (n = 23, 62.2%), communication aids (n = 21, 56.8%), and environment adaptations (n = 19, 51.4%; see *Table 2*). The AT with the fewest associations was controlled (n = 3, 8.1%). Physical environmental modifications were found to be associated with the most diverse types of AT, showing associations with all ten types of ATs. This suggests that the most diverse types of ATs were studied for modifying the physical environments of PwD. Two interventions, caregiver support, and cognitive behavior therapy were associated with nine ATs.

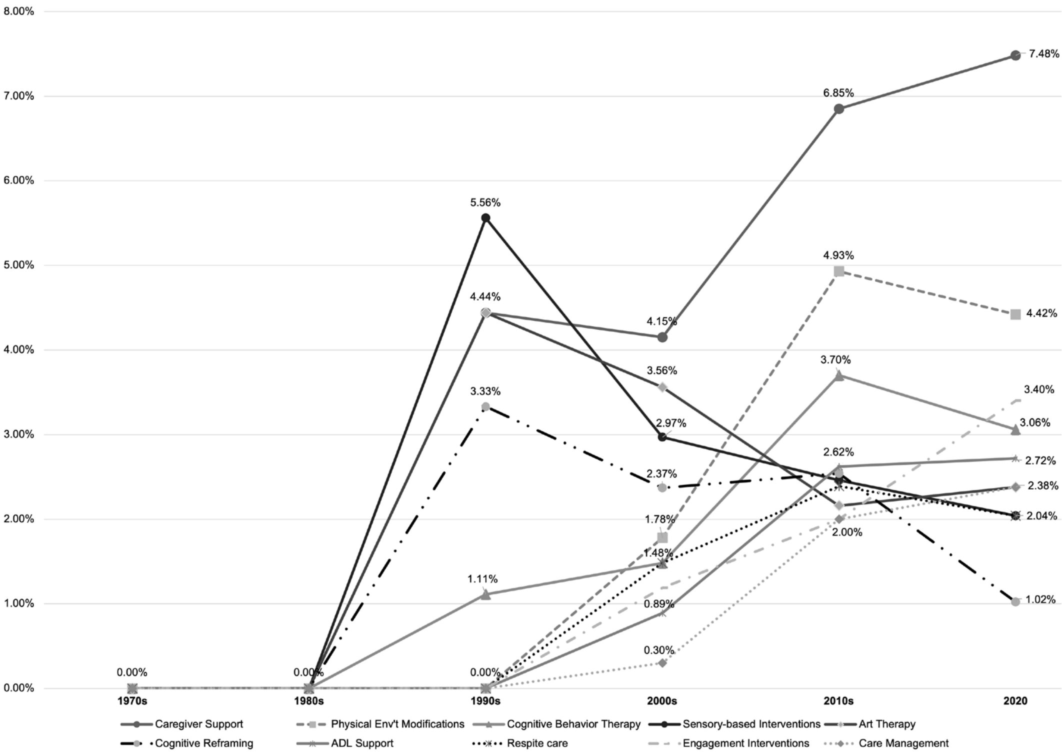

Figure 5. Percentage distribution of articles over the top 10 most frequently identified intervention types per decade from 1970 and 2020

The strongest association was found between environment adaptations and physical environment modification (Jc = .35). This aid also showed relatively stronger associations with ADL support (Jc = .11). These results suggest that studies about ATs for environment adaptations mainly centered on modifying physical environments in a way that support daily activities at home. The second and third strongest association was found between therapeutic aids and cognitive behavior therapy (Jc = .19) as well as recreation aids and robot intervention (Jc = .19). These associations suggest that language-based therapy has been utilized the aids to support emotional regulations such as depression and anxiety. Interventions using robots mainly focus on recreation. Safety and security and physical environmental modification also showed a relatively strong association (Jc = .12). This result confirms when modifying physical environments, safety and security issues were the main focus (*Table 2*). *Figure 6* visually represents the associations among the terms regarding ICTs, ATs, and interventions from the collected literature.

Discussion

To present a holistic and historical landscape of research on how research on ICTs has been conducted in relation to ATs for dementia interventions, this study mined the research articles pertaining to ICTs and ATs in dementia, that were published between 1970 and 2020. Distribution patterns and associations among the categories of ICTs, ATs, and interventions found in this study revealed how research interest in integrating ICTs into ATs for dementia interventions has progressed in the last five decades. Two distinct patterns emerged: (a) the movement of integrative approaches to dementia-targeted ATs with ICT elements only recently occurred; and (b) a range of ICTs (e.g., IoT, smart devices, wearable technologies) have been utilized in ATs in a way that can support aging-in-place for PwD.

The distribution patterns of the articles indicate that scientific interest in the integration of ICTs in dementia-targeted ATs started emerging only after the 1990s. The profusion of ICTs in healthcare started in the 1950s and the first implementation occurred in the 1960s in hospital information systems (Rudowski, 2005). Ever since ICTs brought spectacular achievements to healthcare systems such as hospital systems, medical data systems, and diagnoses. However, the findings indicate that ICT adoption in dementia-focused ATs was particularly slower than in other sectors even within the healthcare domain. For the 1950s and 1960s, no articles regarding ICTs in relation to dementia care were yielded in our electronic search. During the next two decades, the 1970s and 1980s, a smaller number of relevant

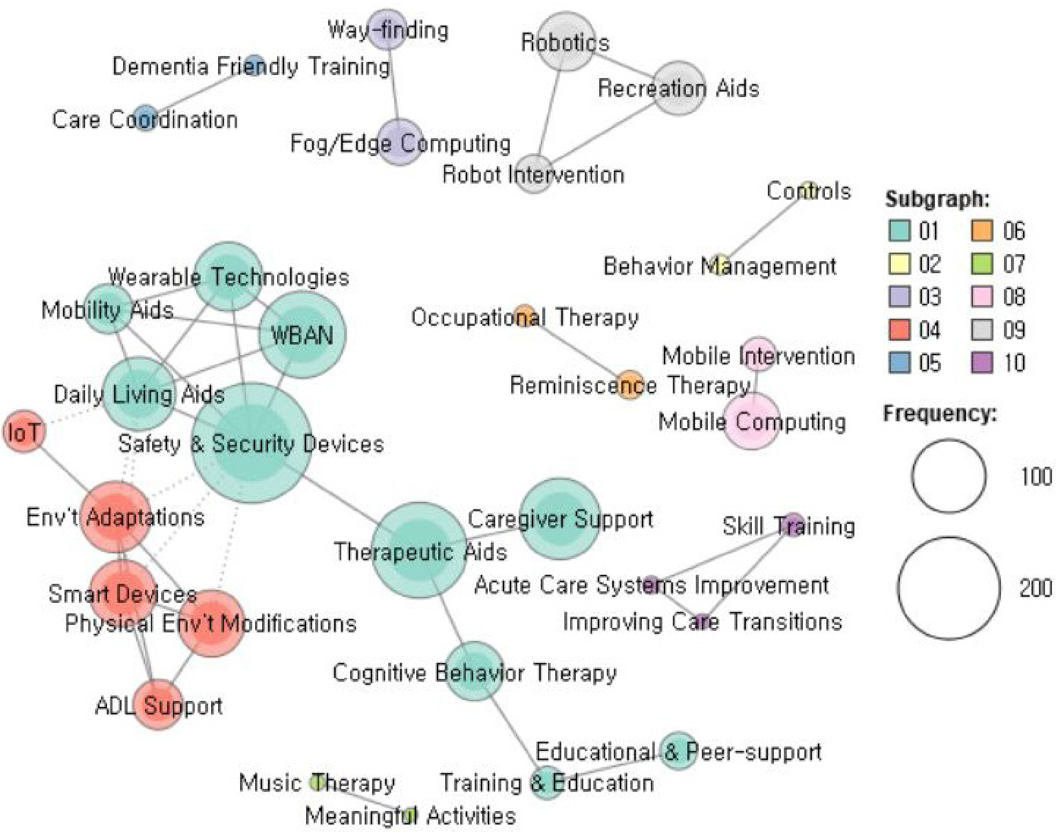

Figure 6. A modular structure of co-occurrence among ICTs, ATs, and interventions categories

articles were searched but none of those articles were found to have addressed ICTs. Only since the 1990s, have three articles been found to discuss ICTs in the area of dementia care. The1990s is typical of significant advanced ICTs development that penetrated almost all areas of our life. The interactive Web 2.0 arrived and showed an incredible amount of growth by enabling anyone to publish and share data online. Besides, more cost-effective data storage became available at a low cost (Aceto et al., 2018). These technical advancements led to the explosive growth of data and the development of big data analytics (Lee, 2017). The big data phenomenon also led to the prosperous application of AI in several industries such as banking, marketing, and entertainment during the 1990s and 2000s. Despite this rapid pace of technological innovations and previous technology adoption to medical systems, only three articles in the 1990s were found to regard with ICTs in AT development focusing on dementia care. This result clearly indicates slow scientific investment in dementia care, even within the broader healthcare sector (Reid et al., 2005).

A range of factors, such as underinvestment and social stigma, may have contributed to this relatively slow adoption of ICTs in dementia care. The healthcare sector is known to have under-invested in technologies compared to other industries (McAvey, 2021). In addition, a limited view toward dementia as purely a clinical matter in the past, with a focus on the physical and mental consequences (e.g., delirium, negative changes in autonomic function, and behavioral disturbances) of the disease, further contributed to slowing down recognition of the benefits of technology for PwD (Spittel et al., 2019). Evidence shows that technology can benefit PwD and their caregivers. For example, Lauriks et al. (2007) concluded that studies regarding ICT-based ATs in dementia care showed that PwD are capable of handling and benefiting from electronic equipment. It is known that even the standard functions of a smart device can also benefit PwD and their caregivers, helping them maintain social connections via calls, texts, videoconferencing, or receiving cognitive stimulation (e.g., playing games) (Astell et al., 2019). However, stigma regarding the illness, viewing PwD largely as incapable and excluding them from society (NCCMH, 2007), limited perceptions of the potential benefits of technological devices for PwD. Building on this view, harnessing the power of ICTs had been questioned in terms of funding and support for everyday tech-

Table 1. Similarity scores between ICTs (N=13) and types of ATs (N=10)

	Daily Living Aids	Therapeutic Aids	Safety & Security Devices	Env't Adaptation Aids	Communication Aids	Recreation Aids	Hearing Aids	Mobility Aids	Vision Aids	Controls	Num. of Associated ATs(%)
Smart technologies	0.10	0.05	**0.10**	**0.39**	0.05	0.02	0.01	0.04	0.03		9 (90.0)
WBAN	**0.16**	0.07	**0.21**	0.06	0.04	0.02	0.03	**0.14**	0.01		9 (90.0)
Robotics	0.05	0.04	0.04	0.02	0.02	**0.17**	0.02	0.05	0.04		9 (90.0)
Wearable technologies	**0.19**	0.04	**0.18**	0.09	0.03	0.01		**0.22**	0.01		8 (80.0)
Mobile computing	0.06	**0.10**	0.06	0.02	**0.10**	0.03	0.02	0.05			8 (80.0)
Big-data	0.08	0.02	0.06	0.06			0.01	0.05	0.01		7 (90.0)
Cloud computing	0.01	0.01	0.01	0.02	0.01	0.03	0.03				7 (70.0)
AI	0.06	0.04	0.03	0.06	0.02	0.02		0.03			7 (70.0)
IoT	**0.20**		0.04	**0.24**	0.01		0.04	0.09			6 (60.0)
Fog/Edge computing	0.02	0.01	0.04	0.02	0.01		0.05				6 (60.0)
WSN	0.03	0.02	0.04	0.02		0.01					5 (50.0)
Social/Interactive media	0.00	0.01			0.02						3 (30.0)
3D Printing	0.01	0.01	0.01								3 (30.0)
Num. of associated ICTs (%)	13 (100)	12 (92.3)	12 (92.3)	11 (84.6)	11 (84.6)	8 (61.5)	8 (61.5)	8 (61.5)	5 (38.5)	0 (0.0)	

nologies (e.g., smartphones), because they are not classified as medical devices except for specific software for cognitive assessments (Astell et al., 2019). Consequently, studies about ATs with ICT elements have been slow to recognize the potential of ICTs for dementia care.

Notwithstanding the slow adoption of ICTs in the domain, the associations appear to reflect paradigm shifts in the aging population, supporting aging-in-place. The associations among the interested topologies indicate that independence of PwD at home while security safety has been the main context of research, offering avenues for ATs with ICT elements that facilitate participation in everyday activities of PwD in their home. Home-based care for PwD is the most important method of caring for PwD (Bosanquet et al., 1997). Independence of PwD at home requires the ability to carry out basic ADLs (e.g., eating, dressing, toileting, and bathing) and instrumental ADLs (IADLs; e.g., managing money, shopping, and getting to places outside the house) without personal assistance (Horgas & Abowd, 2004; Mann, 2005). Considerations for ADL support at home via ICTs were clearly indicated by a large number of associations with and relatively stronger similarity scores between all the identified ICT categories and two types of ATs—daily living aids and environmental adaptation. These associations indicate that ICTs have been examined relative to supporting the daily activities of PwD. The relatively stronger associations between the two ATs—daily living aids and environmental adaptations—and the two types of interventions—home modification and ADL support—further indicate that ICT-enabled ATs have been studied as a means to support the ADLs of PwD at home by modifying the physical environment. The strong associations between the two types of aids—mobility aids and safety and security aids—and the two particular ICTs—WBAN wearable technologies—also demonstrated consideration of safety issues while PwD manage their daily life in their own place and community.

We speculate these research streams reflect a paradigm shift in elder care that has expanded to care for those with dementia. In the past, a typical focus of applications of technology for PwD was issues of safety and security (Czaja et al., 2013; Sixsmith, 2006) to tackle common problems for PwD (e.g., wandering in the community and nursing homes) or possible dangerous situations at home (e.g., flooding, fire, gas leaks) (Astell et al., 2019; Czaja et al., 2013). The key focus of this

Table 2. Similarity scores between types of ATs (N = 10) and interventions (N = 37) with five or more associations

	Therapeutic Aids	Safety & Security Devices	Communication Aids	Env't Adaptation aids	Daily Living Aids	Recreation Aids	Mobility Aids	Hearing Aids	Vision Aids	Controls	Num of associated ATs (%)
Physical Env't Modifications	0.03	**0.12**	0.04	**0.35**	0.06	0.01	0.02	0.01	0.01	0.01	10 (100.0)
Caregiver Support	**0.14**	0.07	0.09	0.01	0.04	0.03	0.01	0.03		0.01	9 (90.0)
Cognitive Behavior Therapy	**0.19**	0.03	0.06	0.01	0.04	**0.10**	0.01	0.02	0.01		9 (90.0)
Sensory-based Interventions	0.02	0.03	0.01	0.03	0.03	0.01		0.01	0.02		8 (80.0)
ADL Support	0.04	0.07	0.02	**0.11**	0.04		0.03		0.02		7 (70.0)
Art Therapy	0.02	0.01		0.02	0.03	0.03		0.01	0.02		7 (70.0)
Behavior Management	0.01	0.01	0.01	0.01	0.01		0.02			**0.11**	7 (70.0)
Educational & Peer-support	0.03	0.01	0.10	0.01	0.01	0.03	0.01				7 (70.0)
Prompts Multicomponent Interventions	0.01	0.01		0.02	0.03		0.02	0.05	0.04		7 (70.0)
Care Coordination	0.03	0.01	0.01	0.01	0.00			0.03			7 (70.0)
Cognitive Reframing	0.03	0.03	0.05	0.02	0.03		0.01				7 (70.0)
Care Management	0.02	0.02	0.01	0.02	0.02	0.01					6 (60.0)
Exercise Interventions	0.05	0.02	0.02		0.02	0.05	0.04				6 (60.0)
Engagement Interventions	0.02	0.01	0.03		0.01	0.03	0.00				6 (60.0)
Respite care	0.01	0.01	0.02	0.02	0.01		0.01				6 (60.0)
Way-finding	0.02	0.03		0.03	0.04		0.03	0.04			6 (60.0)
Mobile intervention	0.07	0.02	0.08		0.03	0.04	0.02				5 (50.0)
Therapeutic Counseling	0.01	0.01	0.01	0.02				0.05			5 (50.0)
Fall Risk Management	0.01	0.01		0.04	0.01		0.02				5 (50.0)
Robot Intervention	0.02	0.02		0.02	0.05	**0.19**					5 (50.0)
Num of Associated Interventions (%)	27 (73.0)	23 (62.2)	21 (56.8)	19 (51.4)	18 (48.6)	18 (48.6)	14 (37.8)	11 (29.7)	6 (16.2)	3 (8.1)	

traditional approach reflects a view of PwD as the incapable and disabled (NCCMH, 2007). In the 1980s and 1990s, a new movement toward dementia care encouraged viewing PwD as individuals with a unique identity and biography and providing care with greater understanding (Kitwood, 1997; NCCMH, 2007). Discourse about independence and active aging have occupied the general older adults in their use of technology (Mann, 2005; Sixsmith & Gutman, 2013). As baby boomers age, however, ensuring they can have an independent life at home will not only relieve the social burden on long-term care services and facilities but also satisfy one of the most common desires for older adults to "age in place" (Cheek et al., 2005). Technology-assisted housing may enable private housing as an option for PwD and can be a target for increased technology to help PwD remain at home longer. The findings of this study indicate that although ATs with ICT elements for dementia have been slow to emerge, efforts now appear to be well underway.

A research gap was also found. Together with independent living, social interaction was found to be a common need in dementia care (Meiland et al., 2007; Naumann et al., 2011). However, the findings of this study indicate that technical assistance to promote social interaction has been understudied. Social connectivity is an area in which technology can offer great benefits for PwD, particularly for those who live alone or at a geographical distance from their caregivers (Ballantyne et al., 2010). The standard functionality of ICT devices (e.g., texting, videoconferencing, and social media) can assist with communication, helping maintain social engagement for PwD to stay relevant and connected to their communities. This sense of belonging is a key component of both the physical and mental health of individuals (Cobb, 1976; Dykstra, 1995; Sixsmith & Gutman, 2013)

Limitations

This study is not without limitations. The analysis results do not take into account the heterogeneity that exists among PwD, such as different stages and types of dementia conditions, which can require different needs. The distinctive characteristics and progression of dementia conditions create variations in needs among PwD and their caregivers. These heterogeneities should be considered in future studies. Methodologically, the researchers tried to capture all morphological variations in the collected literature. However, because the analytic unit was a term, there could be unique terms, including author-generated acronyms or terms, that were not reflected in the code developed for the analysis. Hierarchical relationships among the identified interventions and ATs were ignored because the analysis was limited to terms. Future studies should employ a text-mining tool with categorization capability to consider the hierarchical relations among interventions and ATs. Additionally, together with opportunities, the adoption of ICTs in healthcare introduced or exacerbated issues, such as privacy and security concerns, that were not included in this study. Lastly, claims in this study were made based on definitions and interpretations of the patterns found in the dataset, not stemming from a theoretical stance. This is mainly due to the nature of our study being more inductive and deductive. With the emerging patterns in the current study, our future study will focus on developing a theoretical position while analyzing scaled data as a next step moving forward.

Conclusion

Having traced the research streams regarding ICT integration with ATs for dementia care in the last five decades, the research has been evolving and moving from issues of safety and security, which had been a typical focus for PwD, to maintaining autonomy in their own place. Such findings may reflect paradigm shifts in aging-related research and practice, supporting aging-in-place, one of the most common desires for older adults. This movement has been slower in dementia care but recently accelerated. On the other hand, although social connectivity is necessary for healthy aging, technical assistance to promote social interaction is found to be understudied.

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Appendix A: Brief descriptions and definitions of main ICTs, ATs, and intervention categories addressed in the current study

ICT categories

- 3D printing technologies, also known as digital fabrication technology, refer to additive manufacturing to create physical objects by successive addition of materials (Shahrubudin et al., 2019).
- Artificial intelligence (AI) is an area of science related to making intelligent machines, using the ability of computers to perform human intelligence (McCarthy, 2007).
- Big-data analytics refers to the science of extracting useful information from large, varied, and complex datasets (Hand & Adams, 2014).
- Wireless body area network (WBAN) refers to noninvasive technology for e-health monitoring based on wireless sensor nodes that are designed to be worn by or implanted in a patient to monitor physiological signals and transmit them to a specialized server (Santos & Motoyam, 2018). This technology utilizes miniaturized smart devices with sensors and communication technology (Crosby et al., 2012).
- Cloud computing is a computational model for enabling "on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (National Institute of Standards and Technology, 2021).
- Fog/ Edge computing encapsulates a plethora of enabling technologies that allow computation to be performed at the edge of the network (Shi et al., 2016) or "a virtualized platform that provides computation, storage, and networking services between end devices and traditional cloud services (Yi et al., 2015, p. 38)."
- Internet of Things (IoT) refers to "the networked interconnection of everyday objects" for interaction via ubiquitous intelligence (Xia et al., 2012)
- Mobile computing refers to portable hardware and adaptive software (Satyanarayanan,

2010) with the key characteristic of "the ability of access critical data regardless location" (Satyanarayanan, 1993, p1).
- Robotics is "the generation of computer-controlled motions of physical objects" (Halperin et al., 2017, p1).
- Smart technology is about technology that "has an inherent ability to gather information on its operating environment or history, to process that information in order to draw intelligent inferences from it and to act on those inferences by changing its characteristics in an advantageous manner" (Goddard et al., 1997, p.130).
- Social/interactive networks, also known as social web or web 2.0, are "the network as a platform, spanning all connected devices … creating network effects through an architecture of participation" (O'reilly, 2005, p. 1).
- Wireless sensor networks (WSN) consist of different types of sensors (e.g., seismic, thermal, and visual) scattered in a physical space to monitor ambient conditions (e.g., temperature, humidity, and pressure) (Raghavendra et al., 2006).
- Wearable technologies refer to devices that can be directly or loosely attached to a person (Godfrey et al., 2018)

These categories are not intended to be exclusive and are a general categorization based on previous literature by Aceto et al. (2018).

AT categories
- Controls include electronic and non-electronic aids that help increase the independence of a person with physical disabilities such as switches, environmental control units, and adapted appliances (Georgia Project for Assistive Technology [GPAT], 2020).
- Communication Aids refer to devices and software solutions that provide a means for expressive and receptive communication for people with limited speech and language (GPAT, 2020).
- Daily Living Aids indicates devices to help perform tasks such as cooking, dressing, and grooming (NIH, 2020).
- Env't Adaptations aids include devices, tools, and applications that modify or build environments such as ramps, grab bars, and wider doorways to enable access to buildings, businesses, and workplaces (NIH, 2020).
- Hearing Aids to help people hear or hear more clearly (NIH, 2020)
- Mobility Aids refer to aids that help a person walk or move from place to place, such as wheelchairs, scooters, walkers, canes, prosthetic devices, and orthotic devices (Medline Plus, 2021).
- Recreation Aids are electronic and non-electronic devices and computer applications that are used to increase participation and independence in recreation and leisure activities of people with disability (GPAT, 2020).
- Safety & Security Devices are products and systems that provide safety and security features and can help reduce the dangers (e.g., wandering, juries at home) associated with dementia such as home security cameras, smart door locks, and lighting (Frontpoint, 2021).
- Therapeutic Aids are "devices, tools, or products designed to provide stability, support, and help you perform everyday tasks with ease (ptHealth, 2022)" such as splinting, bracing, and compression garments.
- Vision Aids are items designed to help people with vision loss or low vision, including screen readers, screen magnifiers, and text-to-speech synthesizers (American Foundation for the Blind, n.d.).

Top ten most frequently identified intervention
- Caregiver Support refers to the provision of health and social care services to support for caregivers of people with dementia to reduce their caregivers' burden (Jackson & Browne, 2017).
- Physical Environmental Modification is defined as strategies that modify the living environment in a way to minimize the psychological and behavioral symptoms of dementia and to promote maximal functional independence (Luxenberg, 1997)
- Cognitive Behavior Therapy is a talking therapy that "help[s] people understand these links between their thoughts, feelings and behaviors, and use this understanding to make positive changes (Stott, 2018, p. 1)."
- Sensory-based Intervention indicates treatments that concentrate on the sensory processing (Smith & D'Amico, 2020).
- Art Therapy is defined as "a form of psychotherapy that uses art media as its primary mode of communication (Deshmukh et al., 2018, p. 1)."
- Cognitive reframing refers to a psychological technique that shifts the way situations, experiences, person, or relationships, and events are viewed. (Vernooij-Dassen et al., 2011)
- Activities of daily living (ADL) Support encompasses support for a range of people's daily self-care activities that support independent living (Lawton & Brody, 1969)
- Respite care refers to "any intervention to give rest or relief to caregivers (Maayan et al., 2014)."
- Engagement Intervention is a person-centered approach that encourages people with dementia "being occupied or involved with an external stimulus (p.300)" by contributing ideas, skills and abilities (Cohen-Mansfield et al., 2009).
- Care management is collaborative care that aims to provide optimal treatment and care for people with dementia and support their caregivers using a personalized array of intervention modules and subsequent success monitoring (Thyrian et al., 2017).

Appendix B: Distribution of number and percentage of articles that contain terms related to ICTs, ATs, and interventions (N= 2,030)

	ICTs		ATs		Interventions			
	Categories	**Num. of Articles (%)**	**Categories**	**Num. of Articles (%)**	**Categories**	**Num. of Articles (%)**	**Categories**	**Num. of Articles (%)**
1	Big-data	155 (7.63)	Safety & Security Devices	282 (13.88)	Caregiver Support	129 (6.35)	Therapeutic Counseling	13 (0.64)
2	WBAN	143 (7.04)	Therapeutic Aids	175 (8.62)	Physical Env't Modifications	83 (4.09)	Care Coordination	13 (0.64)
3	Wearable technologies	88 (4.33)	Daily Living Aids	102 (5.02)	Cognitive Behavior Therapy	63 (3.10)	Exercise Interventions	12 (0.59)
4	Smart technologies	80 (3.94)	Env't Adaptation aids	92 (4.53)	Sensory-based Interventions	53 (2.61)	Fall Risk Management	9 (0.44)
5	Robotics	64 (3.15)	Communication Aids	88 (4.33)	Art Therapy	51 (2.51)	Skill Training	8 (0.39)
6	Mobile computing	60 (2.95)	Recreation Aids	52 (2.56)	Cognitive Reframing	47 (2.31)	Occupational therapy	7 (0.34)
7	AI	51 (2.51)	Mobility Aids	45 (2.22)	ADL Support	45 (2.22)	Behavior Management	6 (0.30)
8	Fog/Edge computing	38 (1.87)	Hearing Aids	26 (1.28)	Respite care	42 (2.07)	Dementia Friendly Training	6 (0.30)
9	IoT	31 (1.53)	Vision Aids	14 (0.69)	Engagement Interventions	40 (1.97)	Acute Care Systems Improvement	4 (0.20)
10	WSN	19 (0.94)	Controls	4 (0.20)	Care Management	34 (1.67)	Advance Care Planning	4 (0.20)
11	Cloud computing	13 (0.64)			Way-finding	28 (1.38)	Palliative Care	4 (0.20)
12	3D Printing	3 (0.15)			Robot Intervention	25 (1.23)	Improving Care Transitions	3 (0.15)
13	Social/Interactive media	2 (0.10)			Educational & Peer-support	25 (1.23)	Music Therapy	3 (0.15)
14					Mobile intervention	20 (0.98)	Psychoeducational Intervention	3 (0.15)
15					Training & Education	18 (0.89)	Dance Movement Therapy	2 (0.10)
16					Pharmacological Intervention	17 (0.84)	Meaningful Activities	2 (0.10)
17					Web-based Multimedia Intervention	16 (0.79)	e-Therapy & e-Intervention	2 (0.10)
18					Psychosocial Interventions	13 (0.64)		
19					Prompts Multicomponent Interventions	13 (0.64)		
20					Reminiscence Therapy	13 (0.64)		
Total num. of articles		1,451 (71.44)		1451 (71.44)				1,412 (69.52)