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Information and Communication Technologies for the Activities of Daily Living in Older Patients with Dementia: A Systematic Review

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Abstract.
Background: Significant innovations have been introduced in recent years in the application of information and communication technologies (ICTs) to support healthcare for patients with dementia.
Objective: In the present systematic review, our goal is to keep track of ICT concepts and approaches to support the range of activities of daily living for people with dementia and to provide a snapshot of the effect that technology is having on patients' self-reliance.
Methods: We reviewed the literature and identified systematic reviews of cohort studies and other authoritative reports. Our selection criteria included: (1) activities of daily living, (2) ICT, and (3) dementia.
Results: We identified 56 studies published between 2000 and 2015, of which 26 met inclusion criteria. The present systematic review revealed many ICT systems that could purportedly support the range of activities of daily living for patients with dementia. The results showed five research bodies: 1) technologies used by patients with dementia, 2) technologies used by caregivers, 3) monitoring systems, 4) ambient assistive living with ICTs, and 5) tracking and wayfinding.
Conclusions: There is a potential for ICTs to support dementia care at home and to improve quality of life for caregivers, reducing healthcare costs and premature institutional care for these patients.

Keywords: Basic activities of daily living, dementia, information and communication technologies, instrumental activities of daily living

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INTRODUCTION

In recent years, there have been significant innovations in the application of information and communication technologies (ICT) to support healthcare for patients with Alzheimer's disease (AD) and

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dementia. These technologies can be used by patients with dementia and caregivers, and can run automatically; in this latter case we referred to them with the term "ambient intelligence" [1]. Many ICT systems are currently being developed and could potentially support a patient with dementia in the activities of daily living [2].

The activities of daily living can be included in two broad classes: 1) Basic Activities of Daily Living (BADL) [3, 4] and 2) Instrumental Activities of Daily Living (IADL) [5].

BADL are physical tasks essential to maintaining one's independence and include the ability to go to the toilet, to feed, to dress, to groom, to bathe, and to ambulate. IADL are typically more cognitively demanding than BADL, and include the ability to successfully use the telephone, do shopping, prepare food, do the housekeeping and laundry, manage medications and finances, and use the transportation means outside of the home (e.g., driving a car, using public transit, or riding in a taxi).

In the early stage of dementia, most people are independent with BADL, but they start to need help with some IADL, especially complex tasks requiring multiple steps or extensive planning [6]. As dementia progresses to the moderate stage, IADL such as working, medication management, and keeping track of personal finances become difficult or even impossible to perform, and a person may begin to need help with BADL. In the moderate phase of dementia, cooking, housework, and shopping may require direct assistance, BADL require assistance for set-up and safety, and completing BADL may be disrupted by neuropsychiatric symptoms (NPS) such as anger, frustration, and difficulty in communicating needs [7]. As dementia enters the severe stage, independence is gradually lost and caregivers must provide consistent direct care with most, if not all, BADL. At this stage, a person must be directly assisted with simple BADL such as eating, bathing, transfers, and walking [8]. Safety issues and wandering require constant monitoring [9], and there is the need to create a safe environment [10, 11].

Therefore, people with dementia experience progressive cognitive impairments, and more innovative approaches need to be developed to help promote independence and maximize quality of life. In this context, ICTs may offer a lot of potential and can make a significant difference in the lives of people with dementia and to their primary caregivers. Indeed, it has been noted that these technologies should be part of a home package and should be provided in a thoughtful, sensitive, and ethical way [12]. However, the overall opportunities that technology could create for people with dementia have not been fully clarified to date. The objective of the present systematic review is to investigate the use of ICTs to support the range of activities of daily living for people with dementia, considering "ambient intelligence" technologies that can be used by patients and caregivers.

MATERIAL AND METHODS

The search analysis was informed by the study's aims, previous reviews using qualitative data, and best practice recommendations in the research literature [13, 14]. We reviewed clinical and epidemiological reports from the international literature published from January 2000 to October 2015. This systematic review was based upon searches of the US National Library of Medicine (PubMed), Ovid MEDLINE, EMBASE, Google Scholar, Web of Science, and Scopus databases. The search queries included the following terms (Information and Communication Technologies OR ICT) combined with terms to determine the outcomes of interest (cognitive AND [impairment OR decline OR disorders] OR Alzheimer's disease OR dementia) and were limited to human studies. Only English language articles were included, due to a lack of resources for translation. Reference lists of included articles and relevant review articles were examined to identify every study which the electronic search strategy may have missed.

Study selection

A single reviewer (GDO) examined abstracts retrieved by the electronic search to identify articles deserving a full review. Full length articles were then reviewed before data were extracted from relevant papers. The inclusion/exclusion criteria used for our review protocol are the following: inclusion criteria were: 1) age $\geq$ 60 years; 2) diagnosis of dementia according to the National Institute on Aging-Alzheimer's Association criteria [15], and 3) widely accepted clinical measures of cognitive impairment, disability, quality of life, and global clinical assessments. Exclusion criteria were: 1) no English language (as we lacked resources for translation) and 2) no diagnosis of dementia.

Data extraction

For the present systematic review, from the 170 records identified through database searching, 57 published studies were deemed relevant. Of these, 12 studies were excluded because they were not focused on the activities of daily living. After assessment of the remaining full-text articles, we excluded other 18 studies, 10 of which did not evaluate patients with dementia, and 8 that were not focused on the use of ICT. Thus, the final list included 27 published studies that were eligible for the current systematic review (Fig. 1).

An inductive approach to the analysis was used. The results section was divided in five categories: 1) technologies used by patients with dementia, 2) technologies used by caregivers, 3) monitoring systems, 4) ambient assistive living (AAL) with ICT, and 5) tracking and wayfinding. Other reviewers (DSA, FR, FC, and FG) provided a detailed summary of each study, including its strengths and weaknesses, as well as an overall review of the category [16, 17]. Through this process, the following items were systematically extracted from the articles: approach, methodology, transparency, strengths, and weaknesses. These were then organized according to theme, in order to provide an overview of the state of the field as a whole. Quality of study reporting was assessed using the Standards for the Reporting of Diagnostic accuracy studies in dementia (STARDdem) [18].

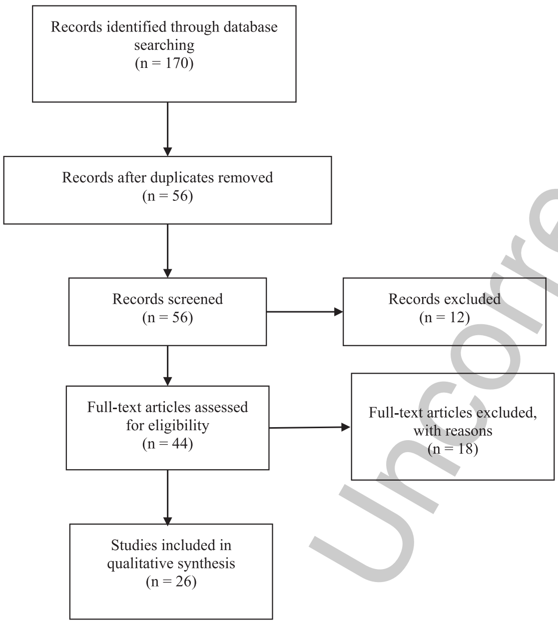

Fig. 1. Flow diagram outlining the selection procedure to identify articles which were included in the systematic review of information and communication technologies (ICTs) and activities of daily living and in patients with dementia.

RESULTS

The potential ICTs that support the range of activities of daily living for people with dementia are shown in Table 1, summarizing the 26 published studies selected for the current systematic review [1, 19–38].

Technologies used by patients with dementia

In the early stages of dementia, ICTs can directly support the patients. Several studies have assessed online resources for patients with dementia focused on maintaining cognitive and functional skills, learning new things, maintaining social interactions, and looking for information [19]. Examples include electronic applications providing reminders (e.g., medication management prompting devices), social contact (e.g., cell phones, online chat groups), safety (e.g., alarm systems and action triggered lighting), and daily activities (e.g., music players).

Technologies used by caregivers

Currently, ICT devices are available to support formal and informal caregivers. An example was the internet-based Savvy Caregiver [20] for informal caregivers. It was based on a face-to-face caregiver-training program and curriculum [21] and consists of a customized computer–telephone integration system that provides a psychoeducational intervention for informal caregivers to identify resources and strategies to enhance safety, self-care, social support, communication, and behavior management [22]. It was shown that this system significantly decreased caregiver burden and depression in informal caregivers [18]. In a pilot study, another type of in-home caregiver support linked informal caregivers with expert guidance for managing challenging care situations using video monitoring, and demonstrated improved behavior management and caregiver communication [23]. Caregivers were trained to capture behaviors that were a problem via computer video recording, which was then wirelessly uploaded to a team of experts to review and provide feedback. Support for caregivers can also be provided through text-based chat forums and web-based video conferencing [24]. A recent study had administered a questionnaire to Canadian unpaid caregivers

Table 1
Current use of information and communication technologies (ICTs) for activities of daily living in patients with dementia according to the identified research areas

Research areas identified	Studies	Methods	Outcomes
Technologies used by patients with dementia	Rosenberg et al., 2011 [19]	AT	To explore actions and driving forces of the actors involved in the process of bringing AT into the life of a person with dementia
Technologies used by caregivers	Hepburn et al., 2003 [20]	SCP	Better caregiver well-being
	Finkel et al., 2009 [22]	E-care	Significant decrease in post-intervention burden
	Lewis et al., 2010 [21]	IBSC	To strengthen family caregivers' confidence in caring for persons with dementia
	Marziali et al., 2011 [24]	2-IBIP	To improve mental health status and improve personal characteristics with associated lower caregiver stress response
	Williams et al., 2013 [23]	IHMSDC	To improve communication and behavior management and ease of use
	Czarnuch et al., 2016 [25]	BADLS	To improve ICT applicability and acceptance for unpaid caregivers.
Monitoring system	Carswell et al., 2009 [27]	AT	To enhance wellbeing and maintain activity levels
	Lexis et al., 2013 [29]	AMT	Support of frail older people to live longer independently
	Doctor et al., 2014 [28]	AI	To better approximate the learnt behaviors and to identify long-term macro-level behavior changes
	Peetoom et al., 2015 [26]	MT	To demonstrate the potential to prolong independent living of elderly persons
Ambient assistive living with ICT	Cook et al., 2009 [1]	AI + VR	To trigger broad empowerment processes induced by a strong sense of presence, leading to greater agency and control over one's actions and environment
	Rashidi et al., 2013 [30]	AAL	To improve safe and independent aging
	McKenzie et al., 2013 [31]	SHP	To ameliorate some of the stress and burden associated with providing care for persons with dementia
	Rantz et al., 2013 [32]	ST	Monitoring individuals' health status, detecting emergency situations, and notifying health care providers
	Jekel et al., 2016 [33]	PFOAT	Smart home technologies offer the chance for an objective and ecologically valid assessment of IADL.
	Realdon et al., 2016 [34]	TEMD	To ensure the continuity of care from clinical practice to the patient's home, enabling also cost effectiveness and the empowerment of patient and caregiver in the care process.
	Lazarou et al., 2016 [35]	IHMS	To monitor problematic daily living activity areas and design personalized interventions based on system feedback and clinical observations.
	Esposito et al., 2015 [36]	SR	To improve the quality of assistive services.
	Wang et al., 2017 [37]	RS	To decrease frustration, stress, relationship strain, and increase social interaction via the robot
Tracking and wayfinding	Chang et al., 2010 [38]	RFID	To serve as good context for triggering navigation prompts, although individual differences in effectiveness varied
	Lancioni et al., 2011 [41]	BOT	To orient their travel and find the rooms correctly
	Grierson et al., 2011 [40]	TWFD	To make the individuals' houses bound and able to perform daily activities without significant frustrations
	Pot et al., 2012 [43]	GPS	Useful for people in early stages of dementia and their informal caregivers
	Pulli et al., 2012 [39]	MATbSNC	Increased awareness of the target users and their relatives or other people in charge
	Tchalla et al., 2013 [44]	HBTec-TS	Reduced incidence of primary indoor falling needing GP intervention or attendance at an emergency room among elderly people with AD and mild-to-moderate dementia
	Lancioni et al., 2014 [42]	AT	Increased positive performance of patients with dementia

AAL, ambient-assisted living; AI, ambient intelligent; AMT, activity monitoring technology; AT, assistive technology; BADLS, Bristol Activities of Daily Living Scale; BOT, basic orientation technology; GPS, global positioning system; HBTec-TS, home-based technologies coupled with teleassistance service; IADL, Instrumental Activities of Daily Living; IBSC, Internet-Based Savvy Caregiver; IHMS, Intelligent Home Monitoring System; IHMSDC, In-home monitoring support for dementia caregivers; MATbSNC, Mobile Augmented Teleguidance-based Safety Navigation Concept; MT, monitoring technologies; PFOAT, Proxy-Free Objective Assessment Tool; RFID, radio-frequency identification; RS, robotic solution; SCP, savvy caregiver program; SHP, Safe Home Program; SR, service robotics; ST, sensor technology; TEMD, technology-enhanced multi-domain; TWFD, Tactile Way-Finding Device; VR, virtual reality; 2-IBIP, 2 Internet-based intervention programs.

of patients with dementia in order to develop a model that uses 13 parameters to predict a person with dementia's ability [25]. The 13 parameters include caregiver relation, age, marital status, place of residence, language, housing type, proximity to caregiver, service use, informal primary caregiver, diagnosis of Alzheimer's disease or dementia, time since diagnosis, and level of dependence on caregiver [25]. Pursuant to the authors of this study, the knowledge of task independence can inform the development of ICT for people with dementia, improving their applicability and acceptance [25].

Monitoring systems

It is recognized that caregiving leads to excessive levels of stress; thus, technology must be tailored to address the determinants of caregiver stressors. For example, caregivers are concerned about the safety and security of their patients with dementia. It is stressful if the caregiver needs to leave the dementia patient at home alone for any length of time or while they work, due to possible wandering, accidents, or other negative events that may harm the patient. ICTs may monitor whether or not the patient leaves his/her home, falls, or enacts other behaviors with potentially dangerous environmental conditions (e.g., heat, water on the floor, and fire). ICTs may alleviate some of these concerns. Many new systems provide these types of monitoring and tracking systems. Three main aims of monitoring are detection of BADL, occurrence of significant events (i.e., falls), and changes in health status, or a combination of these [26].

Monitoring systems are designed to detect changes in one or more BADL or physical parameters. Detection of subtle changes can trigger interventions to avert negative outcomes, such as hospitalizations. An example of a monitoring system is a motion detector that turns a bathroom light on or a wireless home security system that is triggered by exiting or entering, activating an alarm. This technology records information through activity sequence awareness, location awareness, presence awareness, and context awareness capabilities [27].

Alterations in BADL and IADL performance provided objective data about disease progression [28]. Through sensor technology, health care providers were able to detect cognitive decline reflected in behaviors such as getting out of bed at odd hours or going to bed earlier and earlier from day to day [23]. A commercially available example is the QuietCare system, which monitors BADL [29].

Ambient assistive living with ICT

AAL is called "ambient intelligent" and integrates computer technology, electronics, and telecommunications to support people in carrying out their activities of daily life, and maintaining independent living at home [30]. AAL is characterized by "sensors and devices interconnected through a network which senses features of the users and their environment, then reasons about the accumulated data, and finally, selects actions to take that will benefit the users in the environment" [1]. The focus of this technology is to empower human–machine interactions using adaptive, sensitive, and responsive strategies to human needs in digital environments [26]. AAL systems can include multiple sensor devices located within an environment, such as sensor technology, software agents, radiofrequency identification, microchip implant, Bluetooth Low Energy, biometrics, and affective computing.

Examples of complex AAL systems are the smart homes in which remote network monitoring and data exchange at a distance are used. AAL technologies can monitor ambient temperatures, gas levels, and motion, notify problematic changes to remote users, and enable family and health care providers to predict and intervene on impending incidents [31, 32].

The data are collected through infrared sensors (detecting motion on kitchen cabinets while preparing meals) and bed pneumatic sensors (assessing levels of pulse, respiration, and restlessness) [29]. These data are analyzed by developed algorithms to identify functional decline and potential illnesses. Then, health care providers such as nurse practitioners provide timely and effective care to improve and maintain health and functional independence [29]. A recent pilot study had shown that smart home technologies offer the chance for an objective and ecologically valid assessment of IADL [33]. The authors had suggested that one can analyze not only whether a task is successfully completed but also how it is completed [33]. A single blind randomized controlled trial had informed on the efficacy of a technology-enhanced home care service to preserve cognitive and motor levels of functioning in patients with mild cognitive impairment and Alzheimer's disease in order to slow down their loss of autonomy in daily life [34]. The expected outcome was to ensure the continuity of care from clinical practice to the patient's home, also enabling cost effectiveness and the empowerment of patient and caregiver in the care process, positively impacting on their quality of life [34].

A study had proposed a system for continuous and objective remote monitoring of problematic daily living activity areas and to design personalized interventions based on system feedback and clinical observations to improve cognitive function and health-related quality of life [35]. The assistive technology of the proposed system, including wearable sleep, object motion, presence, and utility usage sensors, was methodically deployed at four different home installations of people with cognitive impairment. It has been proved that the proposed system was suitable to support clinicians to reliably drive and evaluate clinical interventions for the improvement of quality of life improvement in people with cognitive impairment and dementia [35].

Advances in service robotics for assisted living applications [36] have facilitated the deployment of ICT Robotics solutions to improve the quality of assistive services. Indeed, another recent study explored perspectives of older adults with dementia and their caregivers on robots that provide stepwise prompting to complete activities in their home [37]. In this study, positive consequences of robots in caregiving scenarios were shown including decreased frustration, stress, relationship strain, and increased social interaction via the robot [37].

Tracking and wayfinding

Dementia patients can be supported in living safely by wayfinding technologies improving independent mobility at home and in the community [38]. Wayfinding systems typically use global positioning systems (GPS) that allow dementia patients in earlier stages to increase freedom, autonomy, and confidence in being able to go outdoors independently and without fear of being lost [39]. Orientation assistance can be given through three modalities, visual, audio, and tactile signals, or a combination, and they have been tested indoors and outdoors [39]. The tactile-based system can use four small vibrating motors attached to a wearable belt with an integrated GPS, three-axis compass, inertial sensor, and an algorithmic executive processor that provides the patients with dementia with direction-relevant cues on which way to go [40]. Regarding this system, the usefulness is limited to dementia patients in mild stages.

Another navigation system using scenario-based video clips embedded with Bluetooth sensor technology was developed and tested with some success on cognitively intact individuals [30]. Studies were conducted on navigational systems using either light or auditory cues, finding consistently that those visual cues were the more effective wayfinding cues for dementia patients [41, 42]. In contrast, tracking devices use similar technology but focus on providing caregivers with a way to know the location of the patient with dementia and to prevent and intervene in unsafe situations. A pilot study evaluated the feasibility and acceptability of a GPS device with expanded features for tracking location and tracing paths through satellite, programming telephone connection between the patients with dementia and the family caregivers, and activating a loudspeaker function to communicate with the patients in case they cannot use the phone [43]. This study found that the GPS intervention increased the ability of the patients to go outside independently, resulting in more freedom from the caregivers and decreased levels of stress for both patients and caregivers [39]. Another example using complex tracking programs was the prevention of night-time falls in patients with dementia. The HBTec-TS tracking system incorporated a nightlight path device that is installed near the bed and was triggered to light up automatically when the person stepped out of bed. The light guided the patient to the bathroom at night [44]. A recent study using the HBTec-TS system reported a significant decrease in night-time falls in the intervention group compared with the control group of community-dwelling dementia patients (odds ratio = 0.37, 95% confidence interval = 0.15–0.88, $p = 0.02$). This system reduced the relative risk of falls by 48.8% in dementia patients at high risk for frequent falls [40].

DISCUSSION

The present systematic review, using an inductive approach to the analysis, identified 21 studies revealing that many ICT systems could purportedly support the range of activities of daily living for dementia patients, showing five principal research bodies: 1) technologies used by patients with dementia, 2) technologies used by caregivers, 3) monitoring systems, 4) AAL with ICTs, and 5) tracking and wayfinding. This increasing body of evidence suggested the potential for ICTs to support dementia care at home and to improve quality of life for caregivers, thus reducing healthcare costs and premature institutional care for these patients.

The purpose of the present systematic review was to investigate the use of ICTs to support the range of activities of daily living for people with dementia considering the technologies of "ambient intelligence" and the technologies that can be used by patients and caregivers. As the population with dementia expands and the burden on family caregivers increases, ICT applications have the potential to support aging in place for patients with dementia while reducing caregiver burden and its negative outcomes, improving quality of life for families experiencing dementia and reducing health care costs. Maintaining independence and a good quality of life might be challenging for some patients with dementia, as for them the activities of daily living are difficult to perform. Thanks to the recent advances in ICTs, they may effectively be used to support older adults in these activities.

In the last ten years, an increasing body of evidence suggested significant benefits in detecting and monitoring early cognitive impairment in AD and other forms of dementia and capturing markers of intra-individual change over time, in real time, and real life situations using ICT devices also in clinical trials [45] or assessing specific cognitive domain (e.g., apathy) [46]. Furthermore, other reviews on ICT use in patients with dementia focused on the activities of daily living also identifying different [47] or specific research areas [48]. In fact, Lauriks and colleagues, in their systematic review on ICT-based services for unmet needs of people with dementia and their informal caregivers, identified need areas including 1) the need for general and personalized information; 2) the need for support to manage symptoms of dementia; 3) the need for social contact and company; and 4) the need for health monitoring and perceived safety [47]. More recently, Teipel and colleagues reviewed only ICT-based possible solutions for supporting outdoor and social activities in patients with dementia, suggesting that ICT services should be proposed at the prodromal stage of dementia and should be carefully validated within the life space of users in terms of quality of life, social activities, and costs. [48]. Very recently, a variety of ICT-based recreational systems have been also developed and evaluated to support patients with dementia in engaging in recreational activities such as social interactions with friends and families or playing games [49].

From our search, we identified 21 studies regarding ICTs that may assist some aspects of ADLs and IADLs in patients with dementia and that, with further interdisciplinary research and modifications, may have potential applications to dementia care. The higher number of ICTs was designed to assist with ambulation, housekeeping, and social communication, whereas a smaller number of ICTs were found to support dressing and toileting. Eventually, the potential for ICTs to support dementia care at home can reduce health care expenditures, secondary to formal care needs and premature institutional care. However, exploiting the potential for technology to meet dementia care needs depends on a number of factors, including raising awareness of available technologies and their utility, promoting accessibility and affordability, and overcoming challenges to acceptance and use. Future research, rigorous clinical trials, and continuous ICT developments are required to improve the use of advanced technologies to be integrated in current dementia care settings. Long term experimentations are essential to assess the real efficacy of ICTs, the acceptability and correct use by patients and caregivers. Moreover, to explore the burden level of caregivers that use ICTs in patient management could be an important indicator of ICT effectiveness. The issue of acceptability and usability was another important issue to explore. In fact, patients and their caregivers are sometimes skeptical about accepting the installation and use of ICTs in their life environments. The investigation of usability and acceptability aspects of ICTs may be fundamental to guarantee the suitability of these solutions in real daily contexts. An idea for future studies could be the implementation of technologies to detect uncorrected emotions and behaviors that can lead dementia patients to a rapid progression of cognitive impairment. Emotion and behavior detection in real time by ICTs could reduce episodes of delirium, onset of NPS, activate rehabilitative and/or relaxing procedures, and improve the performances of the patients in their activities of daily living.

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