When Technology Cares for People with Dementia: A Critical Review using Neuropsychological Rehabilitation as a Conceptual Framework

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During the last decade clinicians and researchers have become increasingly interested in the potential of technology in assisting persons with dementia (PwD). However, several issues have emerged in relation to how studies and reviews have conceptualized who the main technology user is (PwD and/or carer), how technology is used (as compensatory, environment modification, monitoring or retraining tool), why it is used (i.e. what impairments and/or disabilities are supported) and what variables have been considered as relevant to support engagement with technology. In this review we adopted a Neuropsychological Rehabilitation perspective to analyze 253 studies reporting on technological solutions for PwD. We analyzed purposes/uses, supported impairments and disabilities and how engagement was (or was not) considered. Findings showed that the most frequent purposes of technology use were compensation and monitoring, supporting orientation, sequencing complex actions and memory impairments in a wide range of activities. The few studies that addressed the issue of engagement with technology considered how the ease of use, social appropriateness, features of emotion-regulation, level of personalization, dynamic adaptation and carers' mediation allowed technology to adapt to PWD's and carers' preferences and performance. Conceptual and methodological tools emerged as outcomes of the analytical process, representing an important contribution to understanding the role of technologies to increase PwD's wellbeing and orient future research.

Keywords: Technology; dementia; Neuropsychological Rehabilitation; assistive technologies for cognition; engagement

There is a requirement for a tap water control that acts like the carer,
and which does not take control away from the user.
(Orpwood, Gibbs, Adlam, Faulkner & Meegahawatte, 2005)

1 Introduction

Dementia is defined as a clinical syndrome characterized by progressive deterioration in multiple cognitive domains which is severe enough to interfere with daily functioning (Qiu & Fratiglioni, 2011). It encompasses a number of different progressive neurological conditions, such as Alzheimer's disease, vascular dementia and dementia with Lewy bodies, amongst other less frequent sub-types (Clare, 2008). Due to multiple cognitive deficits, persons with dementia (PwD) require increasing support and assistance in order to perform activities of daily living (ADLs). As the condition progresses, PwD and their carers/relatives commonly need to deal with problems such as forgetfulness, disorientation, risk of injury or poor medication management (Georges et al., 2008; Liu et al., 2007). In the last 15 years clinicians and researchers working with PwD have become increasingly interested in the use of technology as a tool to reduce the impact of cognitive impairment in ADLs. Although the adoption of new technologies is frequently challenging, several studies have offered evidence to support the value of technological tools for PwD, in terms of increasing their independence, safety and wellbeing (Cahill, Begley, Faulkner & Hagen, 2007; Topo, 2009).

Due to a large number of studies on the topic of technology use and dementia, since 2009 three comprehensive reviews of historical relevance to the field have attempted to systematize the available information, with rather dissimilar outcomes[1]. Bharucha and colleagues (2009) reported that most available technological solutions in the market were not specifically designed for PwD, and the only three studies involving dementia subjects "relied on small samples and varied in methodological rigor" (p. 100). The same year, Topo (2009) reported a considerably larger number of studies (N = 66) using technological solutions for both the assessment and treatment of PwD. The author concluded that more than half of the studies had as a main goal the use of technology to improve wellbeing and independence, predominantly in the context of residential care. More importantly, most of the studies focused on the needs of the caregivers, while less than a quarter of them actually explored

[1] There are other reviews which we will not consider here since they are topic-specific rather than comprehensive, targeting the use of technology to address particular problems of PwD (e.g. memory).

how PwD used technologies. Finally, Evans and colleagues in 2015 reported a total of over 170 studies. An interesting finding of this review was the overrepresentation of compensatory memory aids to improve ADLs and safety devices compared to the limited number of studies using technology to improve leisure activities. These three reviews have advanced important knowledge regarding how technologies are used to support PwD and their carers. However, they present limitations concerning the conceptualization of the deficits targeted by technological solutions, their intervention purpose, and the facilitation of their adoption and use. These limitations bear important implications for clinical practice as well as technological research and development.

The field of Neuropsychological Rehabilitation (NR) provides an encompassing theoretical framework that can help conceptualizing why and how technologies are/can be used to support PwD. Prior research has highlighted that NR is as relevant for PwD as it is for people with non-progressive brain injury, since it provides a general framework for interventions and a means of tackling specific cognitive and emotional issues that arise as a consequence of neurological and neuropsychological impairments (Clare, 2005; Choi & Twamley, 2013). It has been highlighted in the field of NR that technology is an important tool for reducing everyday problems of people with neurological damage (LoPresti, Mihailidis & Kirsch, 2004; Wilson, 2008). To our knowledge the NR framework has not been used as an analytical perspective to investigate technology-based interventions. However, we argue that the aforementioned limitations can be conceptualized and tackled by leveraging NR perspectives as follows:

1.1 Classification of the main technology user

PwD and their psychosocial support systems are often considered as crucial participants of any NR endeavor, and their involvement usually implies different roles and degrees of participation (Choi & Twamley, 2013). One important conceptual limitation of the aforementioned reviews is the loose classification of studies in terms of who the main technology user is. An example of this problem can be found in the review by Topo (2009), who considered that a PwD was "involved" in the use of a technology if they agreed "to wear a technology such as a transmitter of a monitoring system, at least to monitor physical activity even if not actively influence its functioning and act as informants" (p. 19). In this example it is at least debatable whether agreeing to use a technology or offering verbal reports about it, represent a form of active involvement sufficient to consider the PwD as the main user. O'Neill and Gillespie (2015) have argued that assistive technology must enable, enhance or extend cognitive function when used. Monitoring technologies, in contrast, offer information about the state of the user but do not feed this back to him/her. Similarly, Gibson and colleagues (2016) have proposed that technologies could be classified based on whether they are used 'by' PwD, 'with' PwD or 'on' PwD.

1.2 Conceptualization and analysis of the intervention purpose of technological solutions

Dementia technologies can be used to fulfill different purposes in order to ameliorate PwD's deficits, for example by training cognitive functions or directly mediating ADLs (Bharucha et al., 2009; Topo, 2009; Evans et al., 2015). A systematic classification of such purposes can help understanding how technology can be used and support the design of new technologies for specific purposes. Previous reviews have not accounted for such purposes, focusing on often general and non-systematic descriptions of the objectives accomplished by technological solutions. Based on the categorization of interventions in NR proposed by Mateer & Sholberg (2003), it can be argued that technologies can ameliorate cognitive deficits and improve everyday functioning via *retraining* (improving cognitive functions through practice and stimulation), *compensating* deficits (using residual skills and external support to carry out a task despite the presence of cognitive impairment) or *modifying* the environment (decreasing the cognitive load of certain tasks to optimize PwD's functioning).

1.3 Definition and analysis of the deficits targeted by technological solutions

In order to fully comprehend the scope of a technological solution, this should be analyzed accounting for the cognitive deficits targeted, as much as for the consequences that these deficits may have on relevant activity contexts -disabilities. As noted by Wilson (1997), a confusion of levels may compromise the possibility of performing comparative analyses between different solutions. The aforementioned reviews have not accounted for the multi-level nature of the objectives of a technological solution, thus conflating levels of analysis. NR commonly defines the objectives of an intervention in accordance with the International Classification of Functioning, Disability and Health (ICF, WHO, 1980), which categorizes the sequalae of a neurological condition as *impairments* (damage to physical or mental structures, e.g. language impairment), *disabilities* (restriction or lack of ability to perform an activity, e.g. sustain a conversation) and *handicaps* (impact that impairments and disability have on participation in purposeful daily activities, e.g. work).

1.4 Engagement with technology: conceptualization and analysis of factors facilitating the adoption and use of technological solutions

A central issue that emerges when considering the use of assistive technologies for cognition in PwD is how they engage with technology, and how the designed technological solutions facilitate this engagement process. For any technology to have an impact on wellbeing through its use, PwD must first be capable and willing to interact with the technology. There is abundant literature describing how, due to cognitive impairments, PwD become passive, which often leads to withdrawal from instrumental, social and life-style activities (Kolanowski & Buettner, 2008; Paillard- Borg et al, 2009; Edvardsson et al, 2013; Fernandez-Mayoralas et al, 2015). This emphasizes engagement with technology as a critical process to attend, since cognitive difficulties could impact both the PwD's ability to interact with technology, as well as his/her motivation to remain engaged with it. None of the existing reviews have examined the literature paying attention to this variable.

2 Objectives and Scope of this Review

In light of the above-discussed limitations of previous reviews, the main goal of this study is to critically examine the available literature on dementia and technology using an NR framework to guide the coding, analysis and interpretation of data. More specifically, this review will explore four questions that address the limitations discussed in the previous section:

(1) Question 1 *(Classification of the main technology user)*: Who has been identified as active user(s) of the technological solutions developed for PwD?

(2) Question 2 *(Purpose of technological solutions)*: Considering the main intervention approaches proposed by the NR framework, what intervention purposes have been sought by previous studies through the use of technological solutions?

(3) Question 3 *(Types of impairments and disabilities addressed by technology)*: Which types of impairments and disabilities are commonly addressed by available technologies for PwD?

(4) Question 4 *(Conceptualization of engagement of PwD with technology)*: How have studies addressed engagement, and what strategies have been implemented for its facilitation?

3 Methodology

3.1 Literature search procedure

This literature review followed PRISMA guidelines (Moher, Liberti, Tetzlaff & Altman, 2009). However, since the focus of this article was to map available technological solutions using an NR framework, no assessment of evidence was carried out. Studies were included in this review if they focused on the use of any technological solution for assisting or supporting the various cognitive/socio-emotional needs of PwD. Articles were searched using a pool of keywords based on previous reviews: (dementia OR Alzheimer) AND (assistive technology OR adaptive technology OR adaptive system OR context-aware computing OR affective computing OR assistive device OR monitoring OR surveillance OR tracking OR smart homes). Keywords search was performed as “topic” or in “all field” in four relevant databases: PsychINFO, Medline, Pubmed, and Web of Science. In addition, we surveyed every study included in previous reviews, including Bharucha and colleagues (2009), Topo (2009) and Evans and colleagues (2015). This was an all-time search until 2015 and included only English written studies. A total of 4356 articles from data bases and 290 articles from previous reviews were initially identified. Key information on these articles was consolidated in a database, including authors, title, source and abstract. Articles were then selected for full revision through a two-step process (see Fig. 1).

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As a first step, titles and abstracts were screened in order to exclude duplicated articles and those that were not related to technological interventions for PwD. The main exclusion criteria were: a) articles that did not refer to any form of dementia; b) articles that did not mention any technology-related concept. As a second step, titles and abstracts of the included articles were reviewed again, in order to check the eligibility as defined (studies reporting on technological interventions for PwD). Thus, studies were excluded if they: a) focused on other uses of technology (e.g. to determine causes of dementia, to contribute to the diagnosis or pharmacological treatment of dementias); or b) explored general technological solutions which were not part of a specific intervention. We also excluded literature reviews and theoretical articles.

3.2 Analysis

Two reviewers coded the final 253 articles focusing on the description of the technological solution and its function in addressing specific cognitive deficits and associated functional impairments in ADLs. General information on the studies was also coded and extracted, including: purpose of the study (e.g. development or design of a technological solution, evaluation of an intervention); context (home, residential care home facility, institution);

research design characteristics (e.g. methodology used, sample, etc.); and level of dementia (mild, moderate, severe, mixed).

In order to respond to question 1, the main technology user was coded as patient, carer or both, based on who was the main recipient of information provided by the technological solution, and/or who was its main operator. Technologies that did not target a main information recipient, nor had a main operator, were coded as “no main technology user”.

In relation to question 2, using the classification proposed by Mateer and Sohlberg (2003), each technological intervention was coded as cognitive retraining, compensation or environment modification. Monitoring, carer support and activity recognition also emerged from the coding process as relevant categories.

As for question 3, each technological solution was coded in terms of the impairment/deficit it attempted to address (e.g. spatial disorientation) and the disability/ADL impact originated by such impairment (e.g. way-finding). The classification of cognitive impairments provided by O’Neill and Gillespie (2015) was adapted to guide the coding process (e.g. memory, time and place orientation, sequencing complex actions). Due to the large number of possible disabilities an open coding approach with iterative refinement was adopted to analyze types of impairments in relation to disabilities.

Since engagement was conceptualized as a form of *active involvement* of the PwD with technology, in order to respond to question 4, the search was firstly narrowed to articles where the PwD was actively involved with the technological solution (total sub-sample of 138 studies). The coders then reviewed the methodology section and description of the technological solution in each one of these studies, looking for explicit references to adaptations/features highlighted as factors that can promote and facilitate technology use by PwD. Descriptions of the adaptations/features were extracted from the selected articles, consolidated in a database and subjected to an iterative open coding process. This led to the formulation of general categories of factors facilitating engagement with technology.

4 Results

A first general result of our review is the growing number of publications on this topic, a number that has increased almost eightfold since 2000 (Fig. 2). Half of the studies developed technological solutions to be used at home (n = 128, 51%). Only 48 (19%) of the reviewed studies reported the use of technology in care home facilities. In this setting, just under half of the studies (n = 23) had the carer as the main technology user, and the main goal of interventions was to monitor the behavior of the PwD. Finally, it is important to note that a considerable number of studies (n = 77, 30%) described technological solutions that could be used either at home or in nursing homes.

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A large number of papers did not report the level of dementia which the technological solution was designed for (n = 113, 44%). Most of the studies that considered the level of dementia as relevant for their designs focused on addressing needs of people with mild or moderate cognitive deficits, or at the initial stages of the illness (n = 83, 33%). Only 10% (n = 25) of reviewed studies focused on technology developed for patients with moderate-severe or at late stages of the disease.

4.1 Classification of the main technology user (Question 1)

Data from this review suggests that most technological solutions considered the PwD as an active *technology user.* Just under half of the studies (n = 109, 43%) reported technologies that directly feed information to the PwD in order to facilitate the accomplishment of an activity, thus enhancing, enabling or extending cognitive functions (O'Neill & Gillespie, 2015). A further 12% of the studies reviewed (n = 29) described interventions that actively engaged both carers and PwD, 33% (n = 84) had carers as the exclusive users of the technological solutions.

4.2 Conceptualization of the purpose of technological solutions (Question 2)

We coded 315 different purposes based on the NR conceptualization of interventions proposed by Mateer & Sholberg (2003), and found that 62% of the reviewed studies described technologies focused on compensating, retraining, modifying the environment or a combination of them (see Table 1).

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Technological solutions were most frequently used as tools to *compensate* cognitive deficits, allowing PwD to reduce the impact of a wide variety of cognitive impairments on the successful accomplishment of meaningful everyday activities (n = 131, 52%). The large number of studies using technology as a compensatory tool contrasts with a considerably smaller number of cases in which technological solutions were employed to *modify the environment* (e.g. stove timers used to prevent gas leaks, 19 studies, 8%) or to *retrain cognitive functions* (e.g. computer programs, 18 studies, 7%).

A considerable number of studies conceptualized the purpose of technological solutions outside the classic scope of NR. *Monitoring* is the best example, since 33% (n = 84) of the studies reviewed used technology with such purpose. Technological solutions that monitor PwD (e.g. global positioning system trackers, cameras, motion sensors, bed and fall sensors, position change alarms) were used both at home and care home facilities, usually to collect information from PwD's activities and convey it to relatives or carers. We also found *carer support* to be another relevant purpose of technology, albeit less frequent. 13% of the reviewed studies (n = 33) employed technologies to aid carers, mainly serving to provide education regarding the management of PwD (e.g. Telecare), provide emotional support networks, and facilitate the coordination of different actors involved in the care of a PwD. Finally, *activity recognition* is another purpose associated with the use of technology and not directly related to the NR framework. *Activity recognition* is a process commonly used in smart homes or other intelligent environments, whereby sensory technology recognizes what the behavior of an individual is in order to provide adequate assistive services at the opportune moment (Roy et al., 2011). Activity recognition is a key element in the development of technological solutions that can interpret PwD's behaviors and use such information to feed the user (patient or/and carer) with context-sensitive instructions. 11% (n = 27) of the reviewed studies employed technology for this purpose.

It is important to note that 21% of studies (n = 53) considered technological solutions that combined more than one purpose. The most frequent combinations were compensation-monitoring (n = 16), compensation-monitoring-environment modification (n = 7) and compensation-environment modification (n = 6). The interaction of purposes often occurred in two ways. Some technologies automatically offered information to the carer after the failure of an attempted compensation (e.g. using reminders to take medicines) or environmental modification (e.g. the stove did not turn off). Other technologies offered the possibility for the PwD to ask for help when unable to perform a task on his/her own (e.g. trigger an alarm after a fall).

4.3 Types of impairments and disabilities addressed by technology (Question 3)

A first result regarding impairments and disabilities addressed by technology is that studies rarely classified these explicitly. As Table 2 shows, the most frequently targeted cognitive functions (impairments) were time and place orientation (n = 87), sequencing complex actions (n = 52), memory (n = 47) and communication (n = 44). In many cases, technological solutions were used with different purposes to support the same cognitive function. For example, regarding time and place orientation, technology was sometimes used to compensate (n = 42, e.g. reminding a PwD that is night time so he/she stays in bed), monitor (n = 52, e.g. informing relatives that the PwD has left the bed or bedroom), or modify the environment (n = 16; e.g. turn on the lights when PwD leaves bed to avoid falls). A similar situation was observed in relation to memory. However, in this case technology was more frequently used as a compensatory tool (n = 40, e.g. reminder of an appointment) compared to monitoring (n = 10, e.g. informing carers when the PwD has forgotten to take his/her medicines).

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In relation to disabilities, technological solutions aimed at *compensating* cognitive functions targeted a wide variety of activities of daily living (see Table 3). They were commonly used in helping PwD to scaffold the sequencing of complex actions related to leisure, cooking and bathroom routines. Technologies were also frequently employed to compensate PwD's memory impairments, so that they could keep and follow a schedule, find objects or remember to take medications. Communication and place-time orientation were other domains also commonly targeted.

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Technological solutions used to *modify the environment* were mainly concerned with two key activities of daily living: sleeping and cooking (see Table 4). Regarding sleeping, technology aimed to decrease time orientation problems at night by turning lights on when PwD left their beds, a problem commonly known as night wandering. As for cooking, automatic stoves that turned off when a certain time elapsed or when smoke or gas were detected were commonly used to support PwD's memory impairments by decreasing the cognitive load of tasks.

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When technology was used for *monitoring* purposes, the main goal was to keep the PwD safe while performing different ADLs. In general, monitoring technologies identified situations where PwD experienced difficulties performing an activity, and sent that information to carers so they could offer assistance (see Table 5). More than half of the studies (n = 52) that used technological solutions to monitor PwD's behaviors targeted place and time orientation deficits compromising PwD's capacities to find their way both indoors and outdoors, as well as day/night sleep patterns (night wandering). Walking was another activity frequently monitored by technological solutions, particularly to reduce risks of falls related to balance problems (n = 8). Many technological solutions also incorporated alarms that sent information to the carer when a compensatory intervention failed (orientation in place compensations, n = 6; orientation in time compensations, n = 3; memory compensations, n = 8; balance compensations, n = 3).

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Finally, when technology was used to retrain cognitive functions there was no emphasis on specific ADLs. In other words, cognitive retraining did not address particular disabilities in real life activities. The common underlying assumption in these studies was that by engaging in cognitive drills PwD would improve - or maintain - cognitive abilities. A common limitation of this group of studies was that they either targeted several cognitive abilities (mass training), or did not specify the targeted impaired function (see Table 6).

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4.4 Facilitation of engagement of PwD with technology (Question 4)

In order to respond to this question, all studies where PwD were actively involved with technology were considered for analysis (n = 138). From this sub-sample, only 42% of studies (n = 58) accounted for PwD's engagement with technology when describing the design or application of a technological solution, with varying depth and detail. Most of these studies (n = 38) only mentioned one element of the design that had to be adapted or modified in order to facilitate PwD’s engagement with technology, and only five articles considered three or more adaptations.

The variables considered by researchers in order to facilitate PwD’s engagement with technology were classified as related to the technological solution and to the carer, who mediates the relationship between technology and the PwD (Table 7). In relation to variables related to technological solutions, an important number of studies (n = 32) suggested the need to consider the cognitive demands placed by technology and how these demands interact with the cognitive impairments commonly presented by PwD. This issue was often addressed through developing technologies that were: simple (e.g. few elements to interact with, few steps involved in the interaction and minimum intervention of PwD); reliable (i.e. fault-tolerant, referring to the ability of a system to continue operating in a satisfactory way even in case of malfunctioning of some of its part of erroneous/unexpected interaction with the user); intuitive (requiring a minimal amount of learning, if any at all); as well as cognition-enhancing (e.g. leveraging cognitive strengths to compensate for cognitive difficulties, such as pictorial stimuli and simple language used to facilitate attentional engagement). Some studies (n = 7) also referred to physical features of technological solutions as factors that could potentially influence its use. Size (not bulky), portability (easy to carry), concealability (to avoid looking different) and familiarity (to look similar to everyday life objects) were commonly considered as factors that should be accounted for in order to increase PwD’s engagement with technology.

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The level of personalization of the technology was a particularly relevant design feature implemented to facilitate engagement. An important number of studies (n = 18) referred to this element, in terms of how much a technology fits the PwD’s habitual practices and preferences, and uses personal information to tailor contents and prompts/instructions. Equally important appears to be the emotional experience that a PwD has when using a technology. Several studies (n = 11) mentioned this element, emphasizing that technological solutions must generate positive emotions and avoid triggering confusion and anxiety. Technologies that incorporate social characteristics (e.g. use of friendly voice to convey prompt messages) and reassure the PwD were described as useful to facilitate emotional engagement and consequently improve the emotional experience.

The importance of the interaction between PwD and technology was often emphasized in technological solutions that were capable of monitoring the interaction in real time and use such information to provide ad-hoc responses that facilitate PwD's engagement (n= 12 studies). The best example here were technologies that adjust prompts based on PwD's actual performance (e.g. number of errors, cognitive and sensory status, responsiveness to previous prompts), or use prompts to regulate PwD's psychological states (e.g. confusion, inactivity, boredom, stress) thus reinforcing positive engagement.

Finally, a small number of studies (n = 5) stressed the importance of considering the carer as a key element in promoting PwD engagement with technology. Carers were seen as crucial for the decision-making process (e.g. determine PwD's needs and abilities to use technology, identify more suitable technological solutions, etc.). They were also seen as key to facilitate the use of technology once it was adopted (e.g. reinforce its use; seek help from professionals when there were problems, etc.).

5 Discussion

The main goal of this review was to explore the use of technological solutions for PwD using an NR theoretical framework. Findings showed that PwD are the main users of technological solutions in more than half of the studies (55%). The most frequent purposes of technology use were compensation (52%) and monitoring (33%), commonly supporting impairments in orientation, sequencing complex actions and memory, in a wide range of basic and instrumental activities of daily living. Very few studies explicitly addressed the issue of engagement with technology. By adopting a NR approach our review generated knowledge helpful to gain a better understanding of why and how technology is employed to help PwD and their carers, addressing limitations of previous relevant reviews. In this section we will discuss the theoretical and practical implications of our findings.

5.1 NR as a framework for the systematic analysis of dementia technologies

A key outcome of our work was the formulation of an NR-based schema for the systematic classification of studies - and related technological solutions - based on three key dimensions: purpose of technology, impaired function and targeted activity/disability. The proposal of this NR-based schema responds to the need for theoretical frameworks to understand how technologies consider and address dementia-specific problems and limitations. Based on previous reviews in the dementia field (Marshall & Hutchinson, 2001; Topo, 2009), it can be argued that such understanding is hindered by issues related to lack of conceptual clarity, scarcity of theory-guided research, and diversity of outcome measurements. In particular, Marshall and Hutchinson (2001) stress the importance of striving for methodological rigor and theoretical soundness when conducting research with an already difficult population to study. We believe that the proposed NR-based schema represents a suitable solution to address these issues (Figure 3).

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The classification of intervention approaches proposed by Mateer and Sohlberg (2003) served to categorize the purpose of technological solutions in most of the reviewed studies (62%). Investigating technology purposes in the remaining studies then led us to extend Mateer and Sohlberg's classification with two additional types of technological purposes: carer support and monitoring. Even though carer support is not explicitly included in Mateer and Sohlberg's classification, it has been described as a key intervention in the NR of people with both acquired (Cameron & Gignac, 2008; Evans-Roberts, Weatherhead & Vaughan, 2014; Norup, 2018) and degenerative brain damage (Clare, 2008; Zarit & Edwards, 2008). Concerning monitoring technologies, the NR literature appears not to have paid much explicit attention to such intervention (see later section for a discussion on this topic). Overall, the classification of purposes presented in Figure 3 allowed us to arrange all the reviewed studies based on how technological solutions were used to address specific impairments.

5.2 Expanding the scope of technology-based interventions

This review generated important insights regarding the current dominant scope of technology-based interventions, its implications, and how this could be improved by future research. The vast majority of the reviewed studies focused on using technological solutions to address cognitive impairments in the context of predominantly individual activities. As noted by Wilson (2005), the core goal of NR is the amelioration of emotional, cognitive, and social deficits. Accordingly, technology should address cognitive impairments as much as social and emotional issues. It is clear by the results of this review that this is not the case. Technology appears to have been strongly conceived as a form of cognitive prosthetic, thus tending to neglect social and emotional domains. Data from this review suggests that only a relatively small number of technologies were designed to support PwD’s social relationships, by helping them to communicate with others who are not present (e.g. making a phone call), or scaffolding face to face social interactions (e.g. suggesting topics to include in the conversation). In relation to emotional problems, very few studies focused on managing negative emotions and/or promoting positive ones (e.g. soothing technologies or social pets). However, it is necessary to clarify that the exclusion of emotional and social variables, when designing and implementing assistive technologies for PwD, is a problem that reflects a broader limitation of the field of NR itself. Only recently emotional and social dimensions have become central elements of NR theoretical models (McDonald, 2017; Bowen, Yeates & Palmer, 2010; Wilson & Gracey, 2009), slowly permeating the treatment of PwD (Clare, 2008). As a consequence, the operationalization of these variables, in terms of how to assess and monitor them, both in clinical and research settings, has been significantly slower compared to cognitive functions. A closer consideration of existing models in NR will help researchers to develop and test assistive technologies that can target PwD's emotional and social needs.

5.3 Promoting an integrative approach to the analysis, design and implementation of technologies

Key findings of this review indicate that different technological solutions can be used with different complementary purposes in order to support a given cognitive function in the context of relevant ADLs. For example, a PwD who experiences memory problems and struggles to cook a meal can be helped by a combination of: compensatory technologies (e.g. a reminder about each of the necessary steps to cook breakfast, and a prompt to turn off the stove when the meal is ready); monitoring technologies (e.g. information sent to the carer reporting that the PwD is cooking); and technologies that modify the environment (e.g. a stove with a timer that turns it off after a given amount of time). Such *convergence of technologies* suggests that solutions can be designed as a *system* in which different technological tools can synergistically contribute to the same goal, consisting in addressing a specific cognitive deficit in relation to a specific activity. The development of a system, composed by several strategies that support an impaired cognitive function, is a key theoretical principle in the holistic rehabilitation of cognitive deficits (Winson, Wilson & Bateman, 2017).

5.4 Conceptualizing Monitoring from an NR point of view

As previously noted, monitoring was a highly frequent technology purpose (33%) in the reviewed studies. However, little has been said about this type of intervention in the NR field. In general, monitoring, offers information about the state or location of the patient without feeding this information back to him/her (O'Neill & Gillespie, 2015). It is generally agreed that monitoring allows individuals to be assisted when needed, enabling a degree of independence and guaranteeing the individual's safety (Riikonen, Makela & Perala, 2010). It has also been suggested that the perceived intrusiveness of monitoring can be modulated by using technology in the context of a person-centered approach, overtly tailored to individual needs (Niemeijer et al., 2015). This implies developing and implementing monitoring technologies not just to guarantee PwD's safety, but most importantly to reduce restraints and enhance their capabilities (Niemeijer, Frederiks, Depla, Eefsting & Herthog, 2013). This person-centered use of monitoring technologies is highly coherent with the NR framework.

5.5 Developing a model to conceptualize PwD's engagement with technological solutions

As noted before, engaging PwD in activities requiring the use of technological devices can be challenging, with many PwD struggling even to manage everyday technologies such as credit cards and mobile phones (Nygard & Kottorp, 2014; Nygard & Starkhammar, 2007). However, there is also evidence describing a positive attitude of PwD towards technology, when adaptations are considered in order to facilitate accessibility and support engagement (Dove & Astell, 2017). Results from this review can contribute to advancing a preliminary model of PwD's engagement with technology, based on six categories of interacting factors abstracted from the data (see Fig. 4). This model of engagement with technology should be treated as "work in progress", since further research is needed to explore and include other variables not explicitly mentioned in the reviewed studies (see implementation of safety feature in Shore, Power, de Eyto & O'Sullivan, 2018 and contextual factors in Czaja & Nair, 2012; Karwowski, 2012). In addition, models of PwD engagement in non-technology-mediated activities could provide valuable insights to identify further factors potentially relevant to promote engagement with technology for this population. The *Comprehensive Process Model of Engagement* proposed by Cohen-Mansfield and collaborators (2011), for example, proposes three variables that can affect PwD's engagement with objects, activities and other people which can be incorporated in our model: *environmental characteristics* (e.g. level of lighting and sound in the environment); *personal characteristics* (e.g. demographic characteristics of the PwD; level of cognitive functioning); and *stimulus attributes* (e.g. real/virtual social contact; customization to individual interests and capabilities).

------------------ Insert here Figure 4 -------------------

5.6 Understanding the use of technology as a relationship

As noted in the previous section, there is a growing body of literature interested in how PwD and technological solutions dynamically interact, and how this interaction influences PwD's level of engagement with technology. Among the many features that promote engagement, human-like social interaction capabilities and adaptability to the state of PwD appear to have a key role in promoting positive emotional states and reducing confusion and anxiety. Some authors have conceptualized this dynamic interaction between PwD and technology as a *relationship*. This idea is coherent with studies reporting that people with mild and moderate dementia can feel unconfident and confused when interacting with simple (e.g. alarm clocks, radios) and new technological objects (Bouma, 1998; Nygard & Starkhammar, 2007). Furthermore, there is evidence suggesting that even individuals with mild-stage dementia report a higher "perceived difficulty" in using everyday technology compared to people with mild cognitive impairment or controls (Rosenberg, Kottorp, Winblad & Nygard, 2009). In view of this data, researchers have emphasized the need to consider *relational elements* when developing a technological solution, or introducing one to a PwD, particularly in terms of whether and how the PwD can trust a technological solution, and feel confident that he/she is in control of it (Lindqvist, Nygard & Borell, 2013). A related strand of literature has further developed this idea, suggesting that when interacting with PwD technology should *emulate* a carer, imitating the effective strategies used by the carer, attempting to empower PwD instead of taking control away from them, and encouraging PwD to resolve the problems by themselves rather than doing things for them. This approach would require technological solutions to emulate a typical three stage carer response where information is communicated to the PwD and reassurance is offered (Orpwood et al., 2005): a) provide a reminder (e.g. prompt: "don't forget you have left the tap running"), b) intervene if the user does not respond to the reminder (e.g. prompt: "turn off the tap"); c) let the user know what has been done (e.g. prompt: "your bath is ready. I have turned off the tap"). It is the opinion of the authors that future technology development should incorporate such relational approach in order to target not only cognitive impairments, but also the emotional consequences of experiencing cognitive deficits and using technology as a tool to reduce its impact on everyday life.

6 Limitations and future directions

In sum, and based on the results presented by this critical review, the use of a NR framework appears to bring order and theoretical coherence to a field that has seen a dramatic increase in the number of available technological solutions as well as studies exploring its usefulness in PwD. In our opinion, this framework will allow developers and researchers to understand the place that technologies can have in the rehabilitation of PwD, thus, facilitating a better integration between technological and non-technological interventions. We hope this study also contributes to the field by promoting a shared language between developers, researchers and clinicians, so that comparison and replication between studies become possible. This is perhaps one of the main limitations of the field today.

There are specific limitations of this review that will need to be addressed by future studies. For example, how the level of dementia (mild-moderate-severe) interacts with the use of technological solutions. It is likely that technology plays different roles as PwD move from early to late stages. However, most studies do not consider this variable when designing technological solutions, or conceptualize the level of dementia using dissimilar categories. A related question that requires further exploration is the relationship that technological solutions can have with specific types of dementia, which tend to present particular constellations of cognitive/behavioral deficits and difficulties in ADL. Another limitation of this review is that it doesn’t assess the effectiveness of diverse technological solutions. We believe that such task could be better accomplished by using the NR framework, for example, comparing the effectiveness of technologies according to its main purpose (compensation, monitoring, etc.) and the deficit/disability they target.

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8 Appendix

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Tables

Table 1:

Conceptualization of technological solutions for PwD using a Neuropsychological Rehabilitation framework

	Number of purposes	Percent of purposes	Percent of studies
compensation	131	42	52
environment modification	19	6	8
cognitive retraining	18	6	7
monitoring	84	27	33
carer support	33	11	13
activity recognition	27	9	10
other	3	1	1

Table 2:
Cognitive functions commonly targeted by different technological solution purposes.

	Total studies	Compensate	Environment Modification	Cognitive retrain	Monitor
Time and place orientation	87	42	16	2	52
Sequencing complex actions	52	51	0	0	1
Memory	47	40	9	2	10
Communication	44	44	0	0	0
Balance	14	8	1	0	8
General cognition	8	1	0	10	1
Attention	2	0	0	2	0

Table 3:
Impaired functions and disabilities/activities commonly targeted by compensatory technological solutions [1]

Impaired Function Disability/Activity	n
Sequencing Complex Actions	51
leisure (music – watching TV)	31
cooking	19
bathroom routine	17
making drinks	5
getting dressed	4
table setting	3
drinking water	2
shopping	2
Memory	40
keeping routines	29
finding objects	12
taking medication	12
remembering	7
Communication	44
making a phone call	26
talking	17
Time and Place Orientation	42
keeping time	16
indoor wayfinding	12
sleeping	11
indoor wayfinding	5
outdoor wayfinding	5
Balance	8
walking	8

[1] Total number of studies with compensatory purpose: 131

Table 4:
Impaired functions and disabilities/activities commonly targeted by technological solutions that modify the environment [1]

Impaired Function Disability/Activity	n
Orientation in time	16
sleep	14
Memory	9
cooking	9
keeping routine	1
Balance	1
walking	1

[1] Total number of studies with a focus on modification of environment: 19

Table 5:
Impaired functions and disabilities/activities commonly targeted by monitoring technological solutions [1]

Impaired Function Disability/Activity	n
Orientation place	42
wayfinding out-house	23
wayfinding in-house	14
non-specified wayfinding	4
Alarm when compensation fails	6
Orientation in time	11
sleep	8
Alarm when compensation fails	3
Memory	10
medication	1
Alarm when compensation fails	8
Balance	8
walking	8
sleep (reduce falling when waking-up)	2
Alarm when compensation fails	3
Self-regulation	1
challenging behaviors	1
Sequencing complex actions	1
hand washing	1

[1] Total number of studies with monitoring purpose: 84

Table 6:
Impaired cognitive functions commonly targeted by retraining technological solutions[1]

Impaired function	n
general cognition - non-specified	10
attention	2
spatial knowledge	2
memory	2

[1] Total number of studies with cognitive retraining purpose: 18

Table 7:
Features and aims of factors related to enhanced engagement with technologies

Factor	Features	Aim of adaptation/design
Factors related to the technology	Simplicity	• Reduce cognitive demands
	Reliability	• Reduce cognitive demands • Reduce anxiety
	Intuitiveness	• Reduce cognitive demands
	Cognition-enhancing	• Leverage cognitive strengths
	Not bulky	• Facilitate portability • Facilitate concealability
	Portability	• Facilitate easiness to carry
	Concealability	• Avoid looking different
	Familiarity	• Promote intuitiveness • Promote concealability
	Customizability of contents and their delivery format according to PwD's personal information	• Generate positive emotions • Reduce confusion • Reduce anxiety
	Human-like social interaction capabilities	• Generate positive emotions • Reduce confusion • Reduce anxiety • Promote feelings of safety
	Adaptability to state of PwD and/or environment	• Promote feelings of self-efficacy • Regulate PwD's psychological states (e.g. frustration and anxiety)
Factors related to the carer	Capacity to decide on behalf of PwD regarding technology to adopt	• Determine what the PwD's needs are and which technological solutions are more suitable to tackle these needs • Determine what are the PwD's abilities to use technology, etc.)
	Capacity to facilitate the use of the chosen technology	• Facilitate the use of technology once it is adopted (e.g. reinforce its use; seek help from professionals when there are problems or technological solutions need to be adjusted; etc.).

Figures

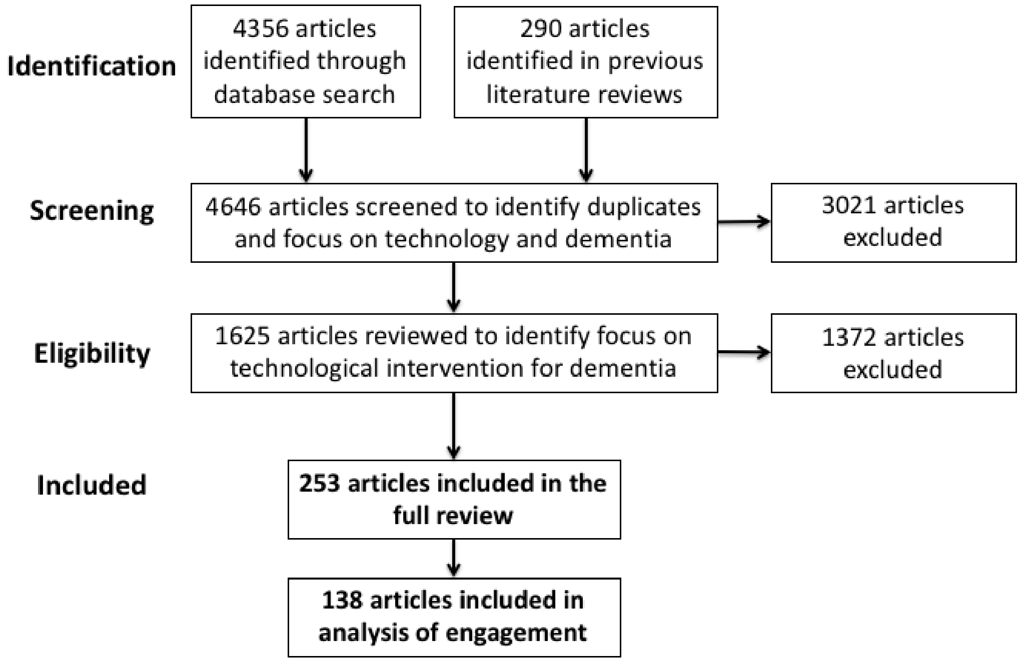

Fig. 1. Process of identification and selection of studies

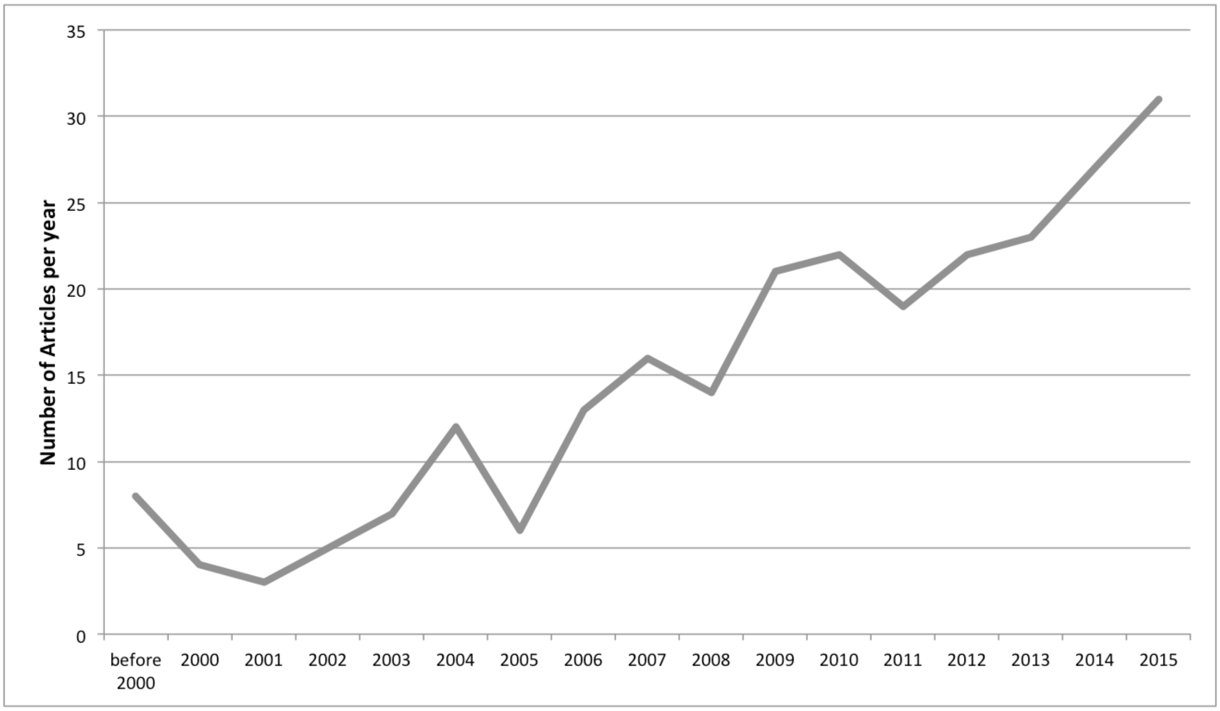

Fig. 2. The evolution of research on technological solutions for PwD from 2003 to 2015

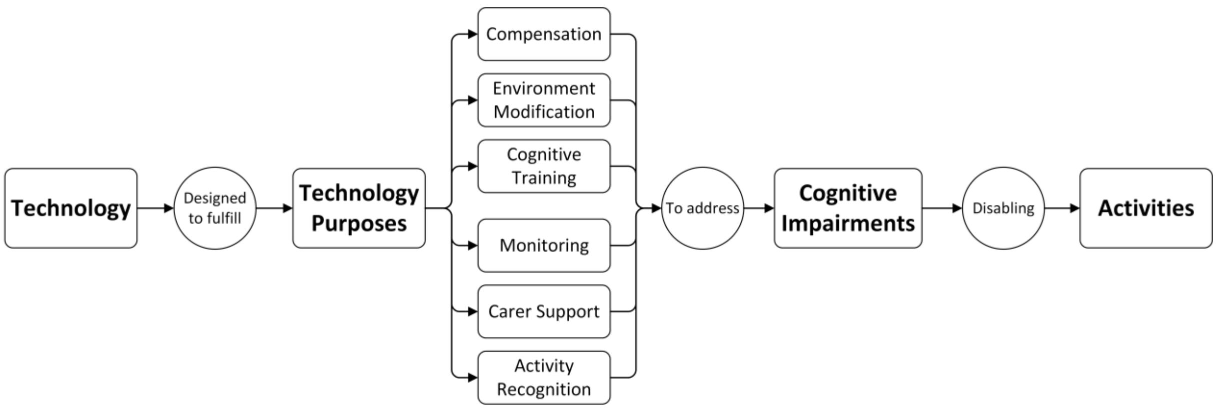

Fig. 3. Neuropsychological Rehabilitation-based schema for the systematic analysis of dementia technologies

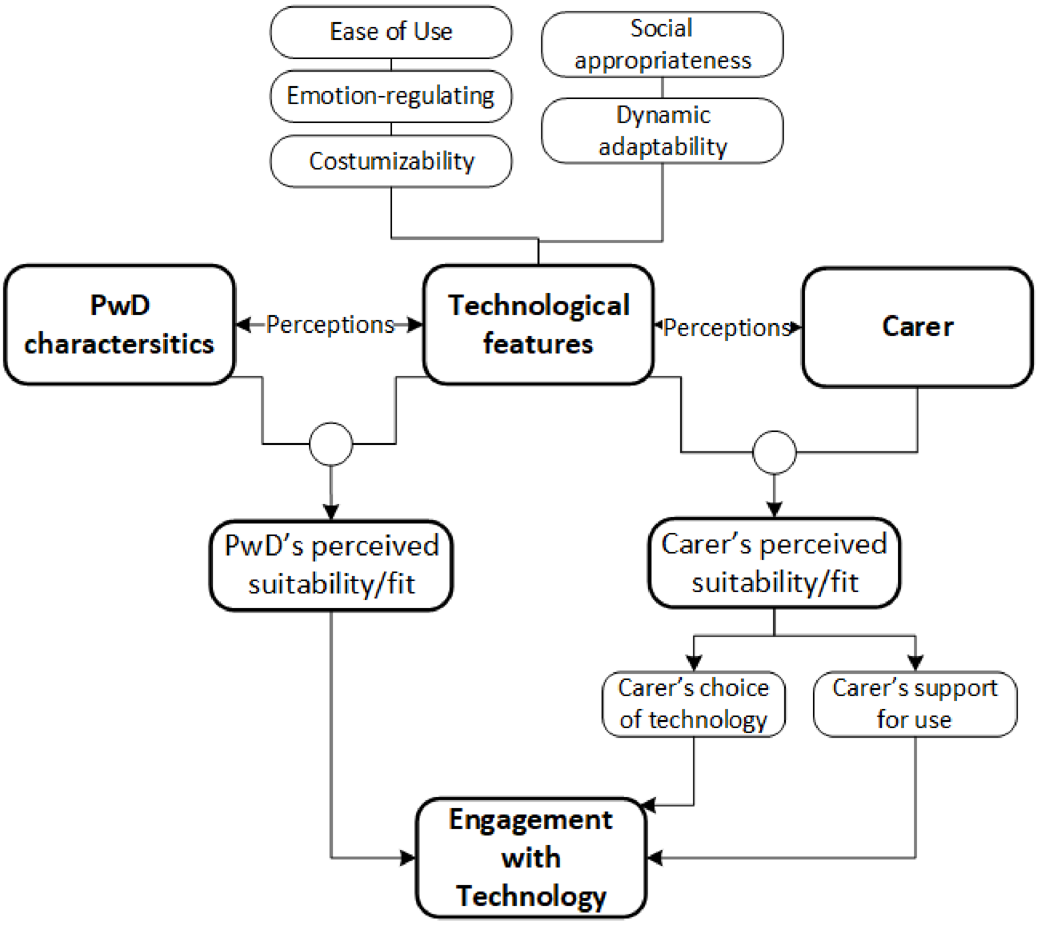

Figure 4: Factors influencing the use of technology

Disclosure Statement

The authors of this paper report no conflict of interests